ISSN: 0976-3104
REGULAR ISSUE
Elias et al.

THE IIOAB JOURNAL

RESEARCH OPEN ACCESS

CERAMIC INDUSTRY WASTEWATER TREATMENT BY RHIZOFILTRATION SYSTEM – APPLICATION OF WATER HYACINTH BIOREMEDIATION

Siti Hanna Elias[1], Maketab Mohamed[2], Aznah Nor-Anuar[2], Khalida Muda[2], Mohd Arif Hakimi Mat Hassan[1], Mohd. Nor Othman[2], and Shreeshivadasan Chelliapan[3]*

[1]Department of Environmental Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310, Skudai, Johor, MALAYSIA

[2]Institute of Environment and Water Resource Management (IPASA), Universiti Teknologi Malaysia, 81310 Skudai, Johor, MALAYSIA

[3]Department of Engineering, UTM Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia, Jalan Semarak, 54100, Kuala Lumpur, MALAYSIA

ABSTRACT

In the present study, water hyacinth was used to treat ceramic wastewater that contains heavy metals such as Cadmium (Cd), Chromium (Cr), Copper (Cu), Zinc (Zn), Manganese (Mn), Iron (Fe), and Boron (B). A batch analysis (3 Columns) by continuous rhizofiltration system was used to remove heavy metals from ceramic wastewater. The metal removal efficiency was identified by evaluating the translocation of metals in roots, leaves and shoot of the water hyacinth. The heavy metal removal efficiency followed the order Fe > Zn > Cd > Cu > B > Cr during the treatment process, and water hyacinth had luxury consumption of those elements (up to 99.3% removal efficiency). In addition, water hyacinth length, weight, stem and leave width were also determined and showed some increment (up to 0.74cm in Column 2). Similar trend was also observed for the leave and stem, where it increased considerably from 5.61 to 6.01 and 2.37 to 2.91 cm in Column 1, respectively. Water hyacinth weight demonstrated some rise (e.g. 27.96 to 37.1 g in column 1), signifying growth of water hyacinth during the treatment of ceramic wastewater. The results of Scanning Electron Microscope (SEM) analyses indicated that most of the metals accumulated in the roots of the plants, suggesting that absorption were the main mechanisms in the treatment process. It can be concluded that phytoremediation of wastewater through rhizofiltration process has the ability to trap and filter contaminants such as metals and organic pollutant.

Received on: 25th-June-2013
Revised on: 21st-Aug-2013
Accepted on: 29th– Aug-2013
Published on: 7th –Jan-2014

KEY WORDS

Ceramic wastewater; water hyacinth; heavy metal removal; rhizofiltration

***Corresponding author:** Email: shreeshivadasan@ic.utm.my; Tel: +603-21805178; Fax: +603-21805188

[I] INTRODUCTION

The production of bricks, clay and sand as raw material for ceramic industry has contributed to certain extent in the field of engineering. It has excellent recycle function primarily in its wastewater usage, where cost has been reduced during formation of the final product and environmentally safe due to waste handling [1]. However, it should be pointed that the ceramic industry also produces a significant amount of wastewater that contains heavy metals. Studies have shown that the ceramic wastewater contains 15 mg/L of Boron and 2000 mg/L of suspended solids [2]. Boron is widely used in the ceramic industry during the development of mechanical strength of tiles. In general, ceramic material is defined as inorganic materials, with possible organic content as well as non-metallic compounds. In addition, it produces a product with a small portion of clay which can be glazed or unglazed, porous or vitrified [3]. A small amount of Boron and metallic elements in ceramic wastewater may affect plant tissues and human body. It is well known that water hyacinth has the capability to absorb mineral compounds. Previous study has shown that it can remove up to 70% of chromium in wastewater [4] and absorb heavy metals such as cadmium and zinc [5]. Water hyacinth is an exotic plant which can grow up to 3 feet and has green leave with sharp edges, circular to oval joined to a spongy reproduction.

Earlier study has shown that metal up-take time and detention area play an important role in phytoremediation, particularly its rhizofiltration [6]. Rhizofiltration is a filtration and absorption process of heavy metals by plant root over a period of time. Response of a plant to hydraulic retention time (HRT) is also considered due to availability of water to retain pollutant. Accordingly, the current treatment method was selected based on economic point of view, and this application may execute in situ plants which grow on ceramic wastewater surface. Even though a number of studies have been conducted on phytoremediation, there were not many studies on ceramic wastewater treatment using water hyacinth. Accordingly, the aim of this study was to investigate heavy metal removal from ceramic wastewater using water hyacinth. The heavy metals investigated were Cadmium (Cd), Chromium (Cr), Copper (Cu), Zinc (Zn), Iron (Fe), and Boron (B). A batch analysis using continuous rhizofiltration system was investigated to remove heavy metals from ceramic wastewater. In addition, psychological response of plant portion to heavy metals absorption and its synchronization to their food was also assessed.

[II] MATERIALS AND METHODS

2.1. Remediation using single plant

Water hyacinth was collected from a Nursery in Skudai, Johor Bharu, Malaysia. The seedling was cultivated using water in a Hydroponic basin (10 L) for a period of 3 days. Ceramic wastewater was collected from a local ceramic factory [Table– 1]. For each batch analysis, around 400 ml of ceramic wastewater was used. The purpose of batch analysis was to ensure adaptability of the plant to ceramic wastewater and growth cultivation. Plant size and weight was determined regularly to choose the best plant for experiment. Later, primary study was performed in 20 L Hydroponic container to investigate heavy metal removal from the ceramic wastewater. In general, around 8 to 11 plants of water hyacinth were specified. The preliminary and primary studies were then performed at 12, 24, 48, and 72 hrs of retention time.

Table: 1. Characteristics of ceramic wastewater

Parameter	Unit	Concentration
pH	-	8.21 ± 0.15
Dissolved Oxygen	mgL^{-1}	0.17 ± 0.02
Chemical Oxygen demand	mgL^{-1}	822 ± 42.0
Total Suspended Solid	gmL^{-1}	0.181 ± 0.11
Boron	mgL^{-1}	14.4 ± 0.20
Copper	μgL^{-1}	20 ± 0.11
Zinc	mgL^{-1}	8.13 ± 0.25
Iron	mgL^{-1}	1.51 ± 0.10
Chromium	mgL^{-1}	19.25 ± 0.02

2.2. Experimental setup

The present study focused on adsorption by root and it is considered as a tertiary treatment of wastewater. A 3-phase cleaning system, with a constant flow rate passing through the 3 columns with different root lengths and distance from first holding tank was proposed for the study, in order to maintain suitable loading and flow rate which consisted a retention pond and rhizofilter. Figure– 1 illustrates the experimental set-up of the study. All variables were identified initially, and wastewater was circulated in one direction in the container (0.28 x 0.19 x 0.46m). Arithmetic mean for the removal efficiency was used when deviation was within 30% of the mean [7].

The experiment was performed by first feeding the ceramic wastewater into a holding tank (0.024m³). Subsequently, the wastewater was fed into Column 1, followed by Column 2 and 3 containing water hyacinth for 5 days. Finally, the effluent from Column 3 was fed back to a holding tank. Since Rhizofiltration focuses on the root system, it is vital to investigate metal accumulation in the root, shoot and leaves of the water hyacinth. Each water hyacinth plant was separated and washed 3 times using distilled water before drying in the oven for 2 days.

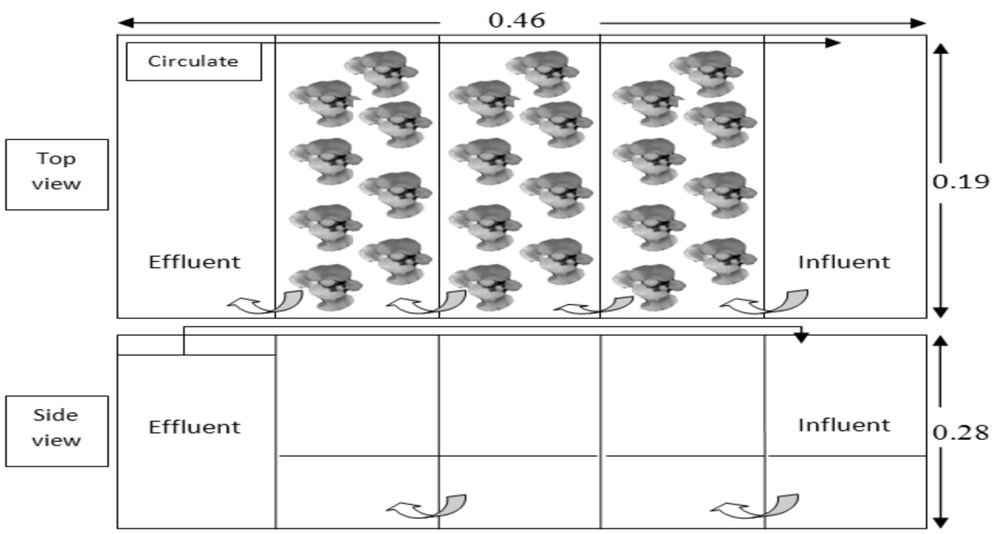

Fig: 1. Schematic diagram of experimental flow (units in m)

ISSN: 0976-3104

[III] RESULTS AND DISCUSSIONS

3.1. The removal of metals with Rhizofilter circulation System

Laboratory experiments with Rhizofilter circulation system were conducted on samples taken from each basin for 5 days. Control tests without plant materials were carried out to reflect on the non rhizofiltration effect in batch experiments. The treatment process is without any circulation with free flow condition. The overall performance of the treatment system is shown in **Table– 2**.

3.2. The performance of metals

Results of heavy metal removal profiles are illustrated in **Figure– 2** to 7 for Boron, Copper, Zinc, Ferum, Chromium and Cadmium respectively.

3.3. Inorganic, Organic Chemical and Physical constituents

The chemical analysis in each column during the treatment of ceramic wastewater is shown in **Table– 1**. The chemical analysis included pH, DO, COD, and TSS.

3.4. Water Hyacinth Performance

Table– 4 indicates the measurement of water hyacinth portion (root, leave, stem and weight). The images of roots are shown in **Figure– 8**.

Table: 2. Heavy metal removal rate (%) and amount reduced in each column containing water hyacinth

Parameter	Control		C1		C2		C3		Effluent	
		%		%		%		%		%
B, mgL^{-1}	3.40	23.6	10.37	72.0	10.90	75.7	10.47	72.7	10.83	75.2
Cu, μgL^{-1}	7.50	37.5	15.00	75.0	15.66	78.3	13.66	68.3	17.66	88.3
Zn, mgL^{-1}	5.13	63.1	7.92	97.4	7.72	94.9	7.92	97.4	7.96	97.9
Fe, mgL^{-1}	1.07	71.2	1.48	98.2	1.48	98.5	1.50	99.3	1.50	99.3
Cr, mgL^{-1}	13.24	68.8	16.53	85.9	16.26	84.5	16.01	83.2	13.24	68.8
Cd, mgL^{-1}	0.10	62.3	0.10	64.8	0.15	93.3	0.15	96.0	0.15	96.0

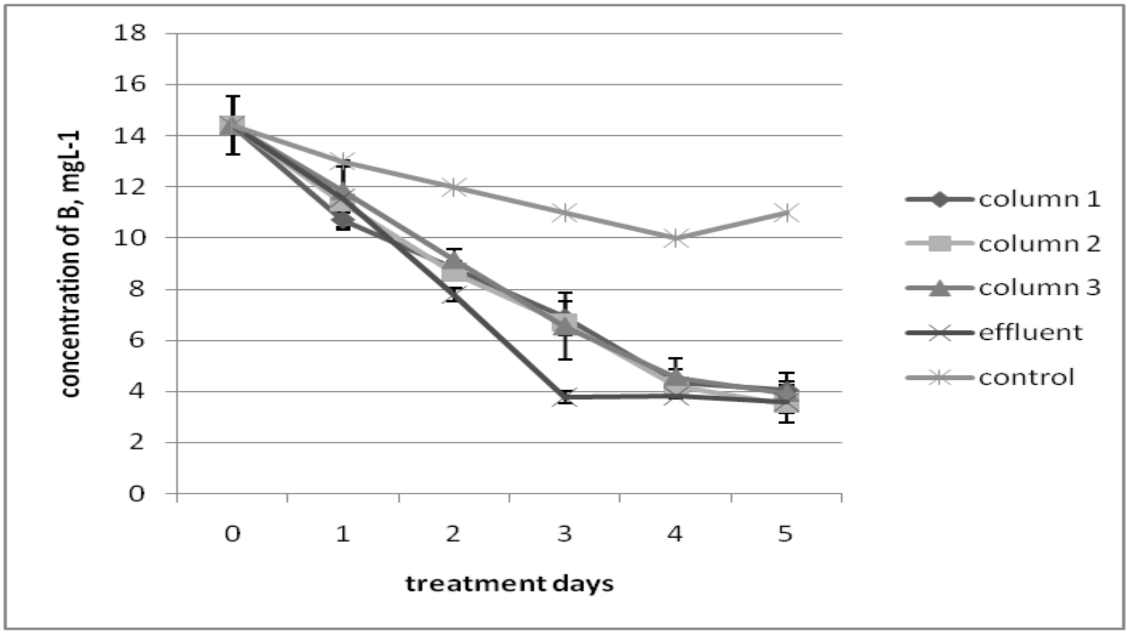

Fig: 2. Boron removal profile in each column during the treatment of ceramic wastewater using water hyacinth

THE IIOAB JOURNAL ISSN: 0976-3104

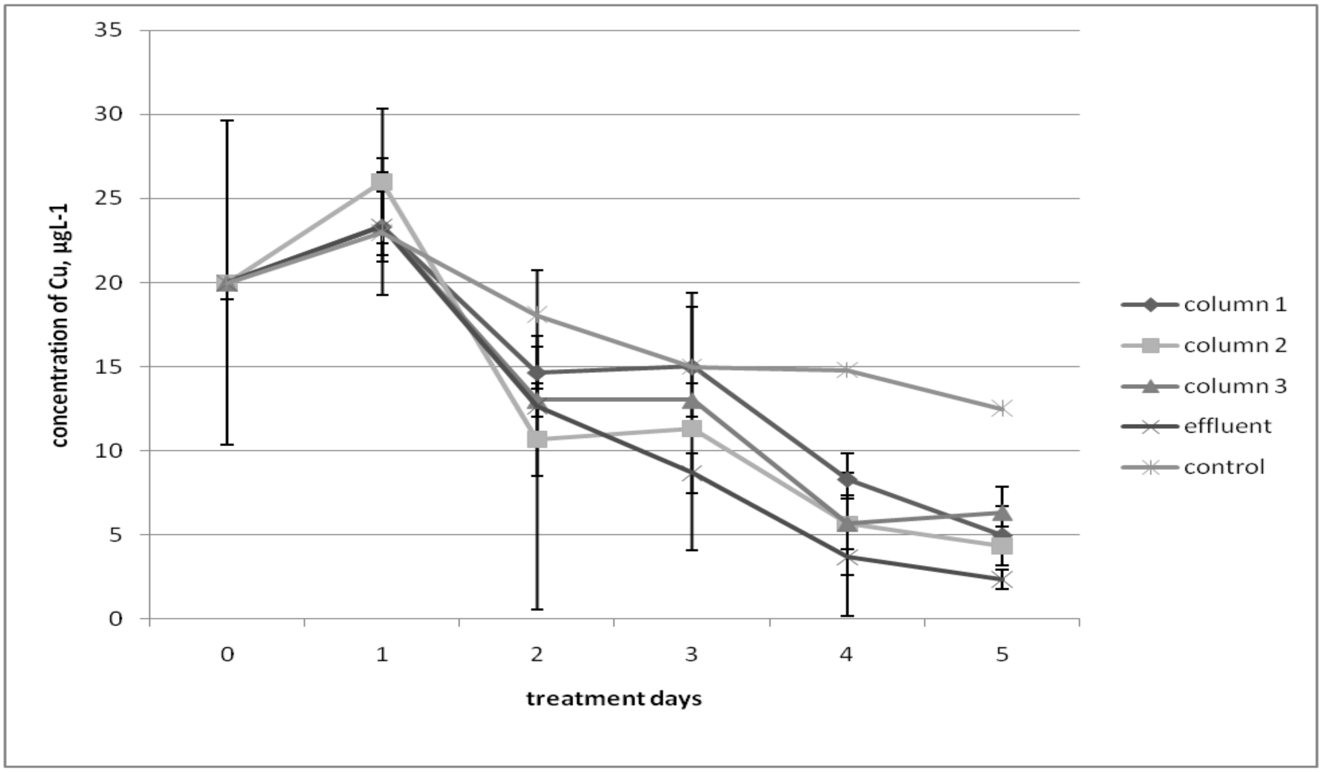

Fig: 3. Copper removal profile in each column during the treatment of ceramic wastewater using water hyacinth

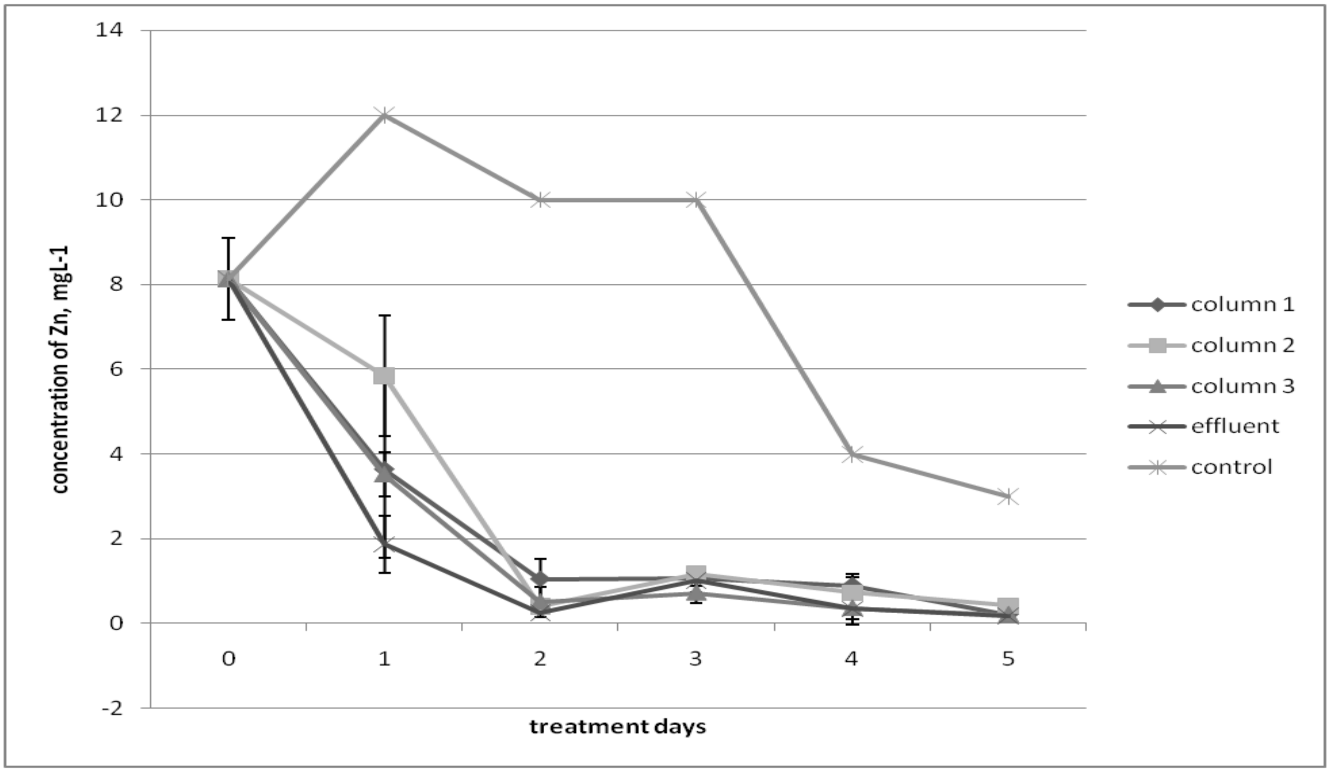

Fig: 4. Zinc removal profile in each column during the treatment of ceramic wastewater using water hyacinth

ISSN: 0976-3104

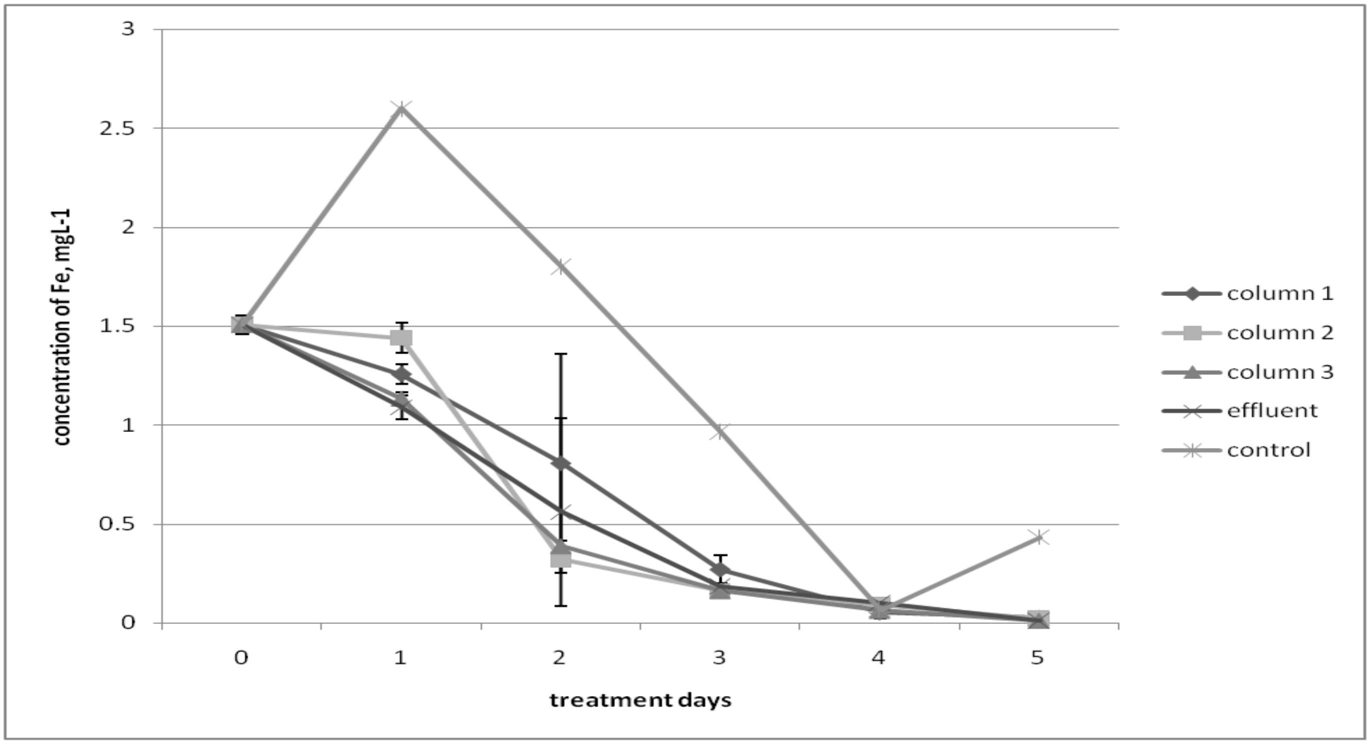

Fig: 5. Iron removal profile in each column during the treatment of ceramic wastewater using water hyacinth

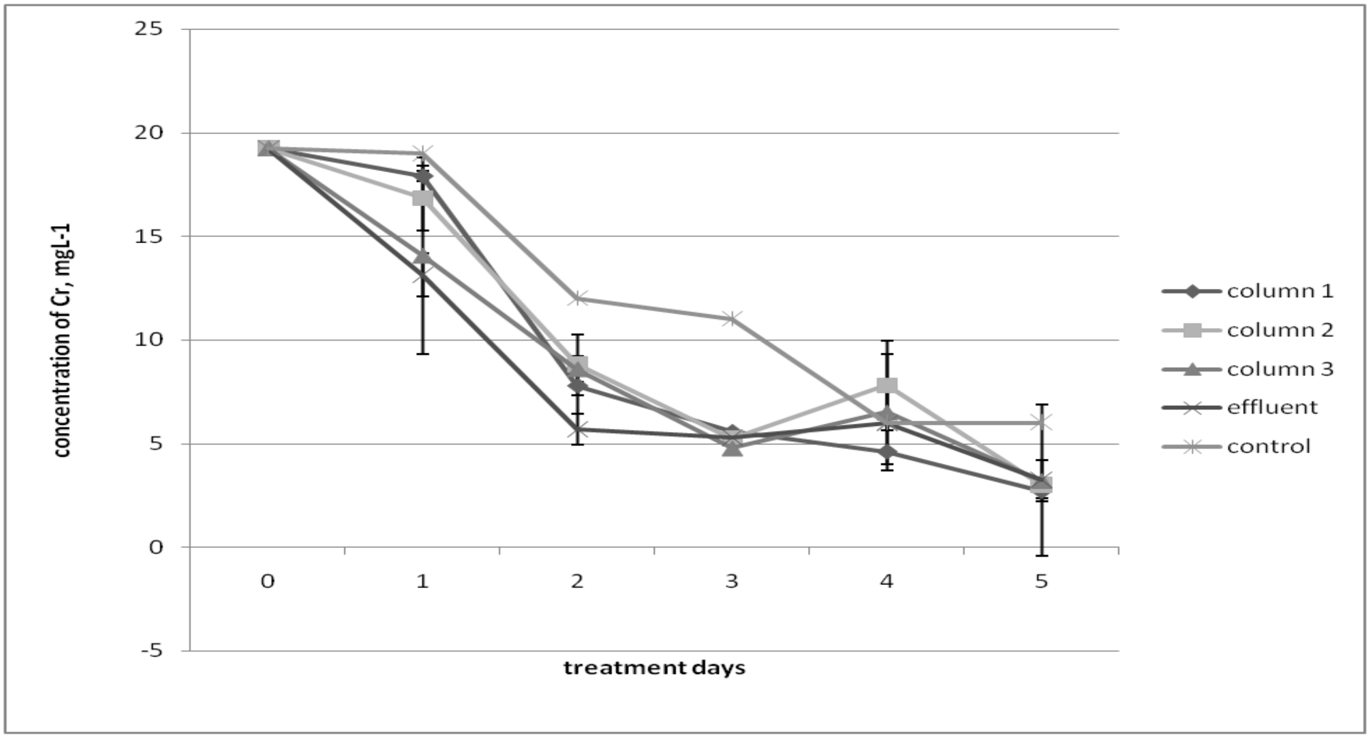

Fig: 6. Chromium removal profile in each column during the treatment of ceramic wastewater using water hyacinth

THE IIOAB JOURNAL ISSN: 0976-3104

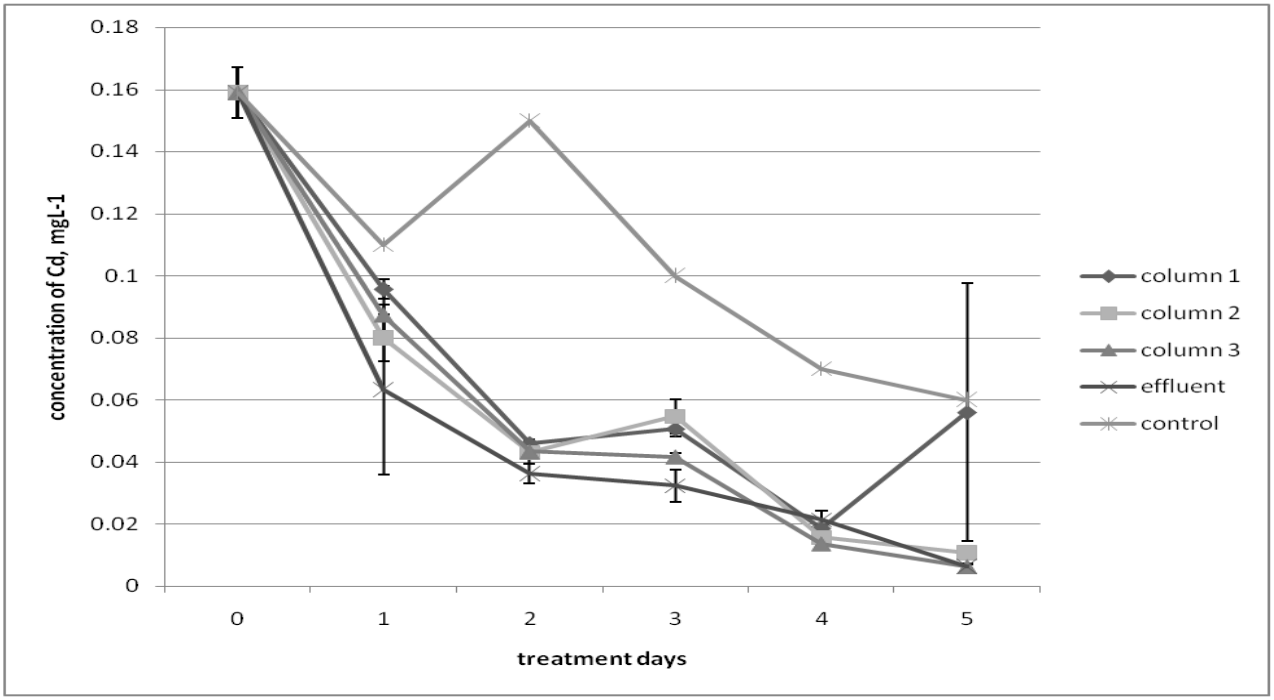

Fig: 7. Cadmium removal profile in each column during the treatment of ceramic wastewater using water hyacinth

Table: 3. Chemical analysis in each column during the treatment of ceramic wastewater

Parameter	Unit	C1	C2	C3	Effluent
pH	-	8.45 ± 0.1	8.49 ± 0.03	8.49 ± 0.20	8.49 ± 0.02
DO	mgL^{-1}	6.71 ± 0.07	6.82 ± 0.15	6.19 ± 0.01	6.52 ± 0.82
COD	mgL^{-1}	160 ± 8	135 ±9.0	124.7 ± 445	101.7 ± 9.35
TSS	gmL^{-1}	0.02 ± 0.01	0.04 ±0.01	0.02 ± 0.05	0.03 ± 0.01

Table: 4. Measurement of water hyacinth's portion

	Initial			5th Day		
	C1	C2	C3	C1	C2	C3
Root length, cm	6.12	4.23	4.35	6.73	4.97	4.73
Leave width, cm	5.61	5.78	5.32	6.01	6.15	5.83
Stem width, cm	2.37	2.11	2.02	2.91	2.56	2.32
Weight, g	27.96	15.97	17.83	37.1	17.25	22.18

[IV] DISCUSSION

4.1. The performance of metals

Figure– 2 illustrates boron reduction profile in each column during the treatment process. It can be seen that boron concentration decreased sharply from 14.4 mg/L to around 3.6 mg/L (75.2% removal efficiency), confirming the removal of boron by water hyacinth. Boron was successfully absorbed (10.83 mg/L, **Table– 2**) by water hyacinth through reaction for growth. It is known that plants need around 0.3 to 1.0 mg/L of boron for growth [8].

As for copper removal rate **[Figure– 3]** it can be seen that it was reduced tremendously, from 20 to 2.4 mg/L in the effluent, confirming the effectiveness of water hyacinth in removing heavy metals from ceramic wastewater. Around 17.66 mg/L **[Table– 2]** of copper was removed in the treatment system. Copper is absorbed by water hyacinth to strengthen its cell and encourages metabolism of nitrogen and carbohydrate in the photosynthesis process [9].

Figure– 4 shows zinc reduction profile, where 97.9% removal efficiency was noted during the operational period. The stem structure of water hyacinth promotes excellent absorption capacity for growth. Zinc activates enzymes for protein synthesis and can be used as starch production and root growth for water hyacinth [10].

Iron is an important element for plant growth, and it is absorbed by roots by rhizofiltration process. Plants have fibrous root, which makes the rhizofiltration process easier [11]. Plants needed this element for enzyme formation that can help photosynthesis. As illustrated in figure 5, the iron removal efficiency increased uniformly from day 3 to 5, with up to 99.3% removal rate.

As for the chromium removal, water hyacinth showed promising results as a hyper-accumulator. The water hyacinth appeared to be a good choice for removing chromium from polluted water. Around 13.24 mg/L **[Table– 2]** of chromium was removed during the treatment process with overall removal efficiency of 68.8%.

One of the main toxic effects of cadmium in plants is growth reserve in size and dry weight of tops and roots [12]. Water hyacinths showed only a minimal adverse impact from cadmium exposure, because of the needs and necessary of nutrient source. Cadmium removal efficiency was 96% **[Table– 2]**.

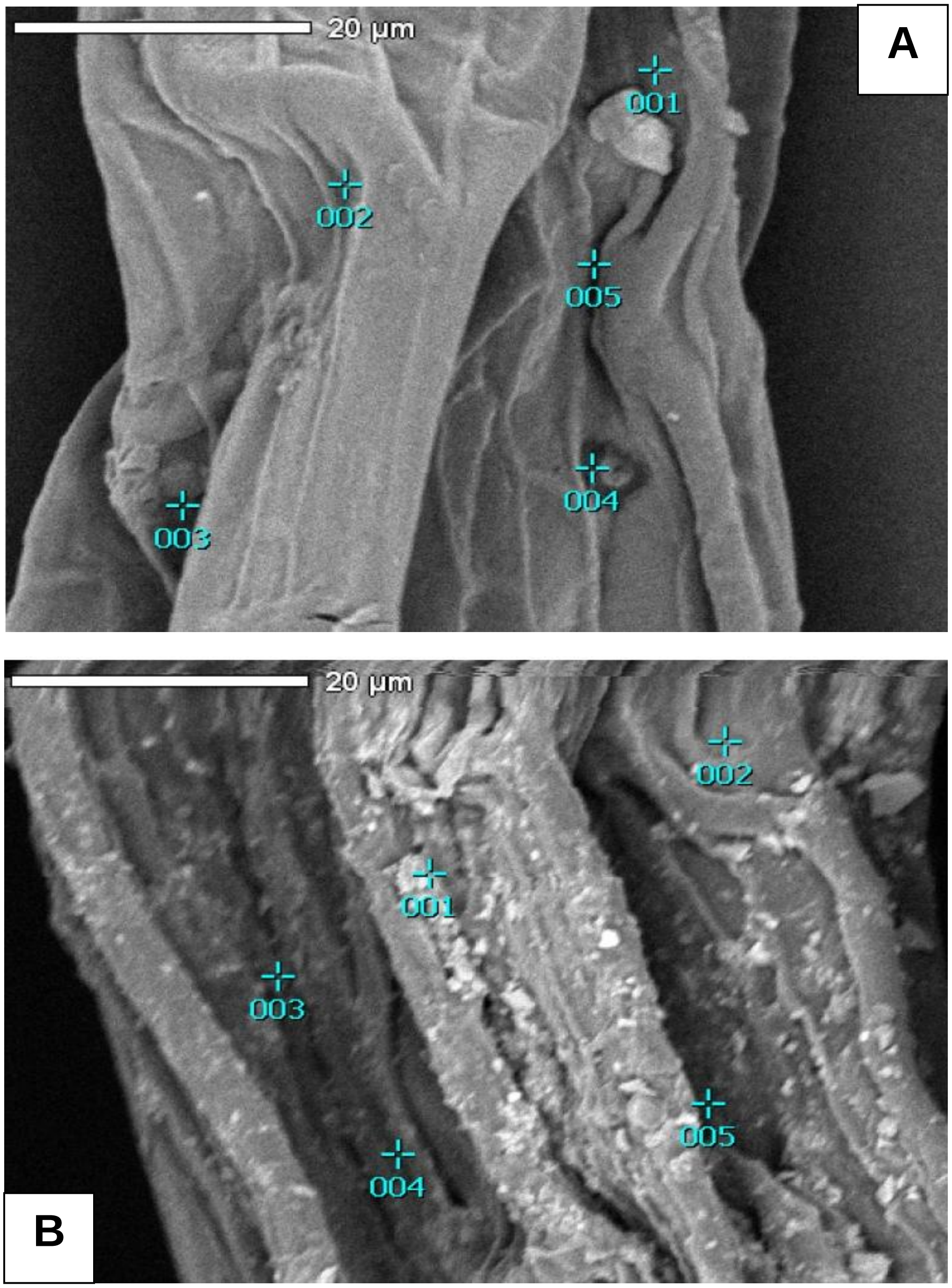

Fig: 8. Scanning Electron Microscope (SEM) images of the surface of the sunflower root (A) before and (B) after rhizofiltration

4.2. Inorganic, organic chemical and physical constituents

Table– 3 illustrates chemical analysis in each column during the treatment of ceramic wastewater using water hyacinth. It can be seen that the pH in the effluent was stable (pH=8.49), confirming the treatment using water hyacinth did not affect the pH profile. However, there was a minor increment in the pH profiles, in all the columns compared to influent pH (pH=8.21), due to chemical reactions that occur during the retention period.

COD removal efficiency can be decreased if a wastewater contains substrates that can be broken [13]. It should be pointed here is that during initial treatment (1st day), the COD in the effluent was around 853 mg/L (data not presented) mainly because of the admixture with existing organic material on the process of wastewater sample and plants relocation. However, the COD removal efficiency increased gradually from day 2 onwards until only 101 mg/L of COD left in the effluent **[Table– 3]**. As for the Dissolved Oxygen (DO), the levels were gradually increased to 6.52mgl^{-1}, due to air supply during the treatment. Oxygen in the sample is used for the decomposition of organic matter by bacteria in the process of aerobic respiration. In addition, the roots played an important role in the aerobic decomposition of organic waste efficiently [14]. Total suspended solid (TSS) for the three sets of water samples were shown in **Table– 3**, and demonstrated some reduction (from 0.181 to 0.03gml^{-1}), probably due to the solid sediments at the base sample. Thick plant roots and high total surface area of water hyacinth promoted sedimentation of suspended solid.

4.3. Water hyacinth performances

Water hyacinth length, weight, stem and leave width was determined **[Table– 4]**, in order to investigate its growth rate. Long heavily roots were seen to increase up to 0.74cm within 5 days of treatment (Column 2). Previous study has shown that the length varies from 4 to 15cm in small plants, 10 to 36cm in medium plants, and 12 to 22cm, in large plants [15]. At certain situations, its populations could be doubled within two weeks. The growth rate of water hyacinth was limited to a certain extent, due to copper contaminations in the ceramic wastewater. Similar trend was also observed for the leave and stem, where their widths increased considerably (e.g. from 5.61 to 6.01 and 2.37 to 2.91 cm in Column 1, respectively). Weight of water hyacinth also showed some increment (e.g. 27.96 to 37.1 g in Column 1) signifying growth of water hyacinth during the treatment of ceramic wastewater. Scanning electron microscope (SEM) [16] showed that the roots were covered with large fragments of heavy metals **[Figure– 8b]**, suggesting that absorption were the main mechanisms in the treatment process containing ceramic wastewater by rhizofiltration.

[V] CONCLUSION

Phytoremediation of wastewater through rhizofiltration has the ability to trap and filter contaminants such as metals and organic pollutants. The circulation process in the current study contributed to the best innovation for the treatment of heavy metals in the ceramic industry. Water hyacinth is appropriate and suitable hyper accumulator for the treatment of ceramic wastewater containing iron, cadmium, chromium, zinc, and boron. Water hyacinth is the best plant because of its luxury consumption with the circulation flow.

CONFLICT OF INTERESTS

Authors declare no conflict of interest.

FINANCIAL DISCLOSURE

This work was supported by Research University Grant (RUG), Vote Number: Q.J130000.2609.02J49 and Q.K130000.2540.03H64.

ACKNOWLEDGEMENTS

The authors thank Universiti Teknologi Malaysia and Ministry of Education Malaysia for funding this project.

REFERENCES

[1] Garcia CM, Quesada DE, VillarejoLP, Godino FJI, Iglesias FAC. [2011] Sludge valorization from wastewater treatment plant to its application on the ceramic industry. *Journal of Environmental Management* 95: 343–348.

[2] Chong MF, Lee KP, Chieng HJ, Ramli IS. [2009] Removal of boron from ceramic industry wastewater by adsorption–flocculation mechanism using palm oil mill boiler (POMB) bottom ash and polymer. *Water research Journal* 43: 3326–3334.

[3] Barros MC, Bello P, Roca E, Casares JJ. [2007] Integrated pollution prevention and control for heavy ceramicnext termprevious termindustrynext term in Galicia (NW Spain). *Journal of Hazardous Materials* 141: 680–692.

[4] Keith C, Borazjani H, Dieh SV, Su Y, Baldwin BS. [2006] Removal of Copper, Chromium, and Arsenic by Water Hyacinths. 36th Annual Mississippi Water Resources Conference, Mississippi State University

[5] Henderson L. [2001] Alien Weeds and Invasive Plants. Plant Protection Research Institute Handbook No. 12. Agricultural Research Council, *Pretoria:* 1–300.

[6] Stout L, Nusslein K. [2010] Biotechnological potential of aquatic plant–microbe interactions. *Current Opinion in Environmental Biotechnology* 21: 339–345.

[7] Lee MH, Yang MJ. [2010] Rhizofiltration using sunflower (Helianthus annuus L.) and bean (Phaseolus vulgaris L. var. vulgaris) to remediate uranium contaminated groundwater. *Journal of Hazardous Materials* 173:589–596

[8] Weiner RW. [2012] Applications of Environmental Aquatic Chemistry: A Practical Guide. Third Edition. CRC Press taylor & francis group, pp–496.

[9] Hammad DM. [2011] Cu, Ni and Zn Phytoremediation and Translocation by Water Hyacinth Plant at Different Aquatic Environments Australian. *Journal of Basic and Applied Sciences* 5-11: 11–22.
[10] Mufarrege MM, Hadad HR, Maine MA. [2010] Response of Pistia stratiotes to Heavy Metals (Cr, Ni, and Zn) and Phosphorous. Arch Environ *Contam Toxicol* 58: 53–61.
[11] Nedelkoska TJ, Doran PM. [2000] Hyperaccumulation of cadmium by hairy roots of Thlaspi caerulescens. *Biotechnol Bioengineering* 67: 607– 615.
[12] Benavides MP, Gallego SM, Tomaro ML. [2005] Cadmium toxicity in plants. *Braz J Plant Physiol* 17: 21–34
[13] Donald M Kent. [1994] Applied Wetlands Sciene And Technology, Leweis Publishers, United States: University of Michigan, 221–226/229–232.
[14] Narendranathan N. [2004] Leachates in Landfills Notes. Workshop on New Technologies for Cost Effective Landfill Management, Kuala Lumpur
[15] Penfound W, Earl T. [1948] Biology of water hyacinth. *Eco. Monogr* 18: 447–472.
[16] NIAST. [2000] Methods of Soil and Plant Analysis, *National Institute of Agricultural Science and Technology*.

ABOUT AUTHORS

Siti Hanna Elias *Siti Hanna Elias is currently a Masters student in the field of environmental engineering.* ***Prof. Dr. Maketab Mohamed*** *is a director of OSHA at UTM.* ***Dr. Aznah Nor-Anuar*** *is a senior lecturer in faculty of civil engineering.* ***Dr. Khalida Muda*** *is a senior lecturer in faculty of civil engineering.* ***Mohd Arif Hakimi Mat Hassan*** *is currently a Masters student in the field of environmental engineering.* ***Dr. Mohd****. Nor Othman is a lecturer in faculty of civil engineering.* ***Assoc. Prof. Dr. Shreeshivadasan Chelliapan*** *is an academic manager (corporate relations) at School of Graduate Studies.*

ENV BIOTECH