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Energy production and wastewater treatment using *Juncus*, *S. triqueter*, *P. australis*, *T. latifolia*, and *C. alternifolius* plants in sediment microbial fuel cell

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ABSTRACT

Sediment microbial fuel cell (SMFC) is a simple and low-cost wastewater treatment technique that uses natural plants to treat a variety of contaminates. It is able to improve the wastewater quality and make it possible for reuse and producing energy along with the treatment process. In the present study, a comparison has been made between five aquatic and semi-aquatic plants, *Juncus*, *Schoenoplectus triqueter*, *Phragmites australis*, *Typha latifolia*, *Cyperus alternifolius*, in order to detect the optimal plant in wastewater treatment to generate energy. Vertical flow constructed wetland adopted in feeding the SMFC with Al-Rustumiya crude wastewater. Samples of the treated wastewater were taken every 3 d. The results showed a maximum reduction in chemical oxygen demand with a value of 91.4%, 90.4%, 86.6%, 73.3%, and 72.3% for *S. triqueter*, *T. latifolia*, *P. australis*, *Juncus*, and *C. alternifolius*, respectively, and total suspended solids value of 86%, 80%, 79.6%, 78.4%, and 64%, and PO_4 values of 70.8%, 66.6%, 66.6%, 62.5%, and 58.3% for *P. australis*, *S. triqueter*, *C. alternifolius*, *T. latifolia*, and *Juncus*, respectively. For NO_3 removals were 81.4%, 80.9%, 80.9%, 80%, and 66.6% for *C. alternifolius*, *T. latifolia*, *P. australis*, *S. triqueter*, *Juncus*, and respectively. Heavy metals were removed as to be non-detected by the testing device from the first sampling process after initial values of 0.07 ± 0.01 ppm for Pb, 0.04 ± 0.02 ppm for Cu, 0.02 ± 0.01 ppm for Cd. The initial pH was 7.9 ± 0.02 and decreased to the minimum possible value of 6.7 ± 0.08 for *C. alternifolius* electricity generation performed better in *Cyperus* and *P. australis* and reached the maximum output of 43 ± 4 mV and 34 ± 3.1 mV on the third day of operation. The findings illustrate that all of the used species were proficient accumulator plants for phytoremediation of these pollutants and could be arranged ascendingly, *P. australis*, *C. alternifolius*, *S. triqueter*, *T. latifolia*, *Juncus*.

Keywords: Sediment; Microbial; Wetlands; Vertical flow; Aquatic macrophyte; Heavy metals; Phytoremediation

1. Introduction

A global warming phenomenon exposes the earth to a high temperature which leads to the following contrasts; (ice river milting) glaciers melting, drought, sudden rainfall and season fluctuations. Cover of greenhouse gases that surround earth increases in thickness on daily basis, which leads to more trapped heat than the earth's needs. Fossil fuel is considered the main reason and it may cause serious problems if not reduced. Besides, fossil fuel is not a renewable energy source and it would be depleted in the future, in such circumstances, nature has granted us a simple solution, which is resorting to renewable sources. These sources are renewed naturally, from sun, wind, water, heat, plants and microorganisms.

A plant microbial fuel cell (PMFC) or plant associated with sediment microbial fuel cell (SMFC) (plant-associated SMFC), a biological cell, has the ability to convert the solar

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energy into the bioelectricity pertained to the microbes at the rhizosphere region of the plant, qualifies to be as an emergent source of sustainable energy. Given the fact that it harnesses wastewater for the treatment by the close circuit of electron transfer and microbes in wastewater itself and contaminants absorbed by plants. SMFC is an appealing choice for the future green energy scheme [1,2].

In contrast, SMFCs can continuously generate energy, and they are considered a low cost engineered system and easy to construct. They depend on anode and cathode. Anode positioning is the most significant factor which is buried in the deepest point of sediment to avoid exposure to the oxygen [3,4]. When the sediment is filled with organic matter- by feeding the sand with wastewater, microorganisms are able to convert these complex matters into simpler ones by metabolizing process. This process could produce protons and electrons. As the SMFC does not have to be supplied with the proton exchange membrane because of redox gradient already exists in SMFCs [5], protons are transferred to the cathode region and react with oxygen-producing water molecules. While electrons are transferred to acceptor electrode (anode) then (traveling) conveyed by conductive wire to donor electrode (cathode) resulting in electricity. The purpose of the plant is hidden behind the photosynthetic in order to synthesize glucose for plants and adds the excess into the rhizosphere as organic matter for sediment microorganisms [6].

The selection of plants is one of the most important steps towards wastewater treatment. Tolerant plants for SMFC climate conditions, the toxicity of wastewater, hypertrophic waterlogged conditions, growth, pests, etc. increases the survival expectancy to a great extent. Wetland plants are used uptake pollutant technology and accumulate them in roots, stems, leaves or any other part of the plant. After accumulation, the plant is either manually harvested or has the ability of self-pollutant extraction by the volatilization method. At the same time, the highly developed root system could release oxygen into the rhizosphere providing the subsurface-flow constructed wetlands (CWs) for aerobic degradation of oxygen [7].

SMFCs require an area for plant establishment. The best choice is the wetland which could be either naturally or artificially CWs [8]. They are designed to utilize some natural processes for wastewater treatment and energy generation [9]. CWs were used in North America in order to promote domestic wastewater purification [10] with free surface flow type and in Europe with horizontal subsurface flow type [11]. Recently, CWs have been stretched to treat industrial wastewater [12] agricultural drainage waters [13], urban and highway runoffs [14]. CWs comprise various treatment processes such as filtration, sedimentation, adsorption, and plant uptake, various microbial processes, precipitation, volatilization, etc. [15,16]. However, these processes are influenced by the circumstances of CWs for instance, temperature, pH, Solar light, plant physiology, redox condition, etc. [17,18]. According to the type of plants, CWs are divided into two types of flows with other sub-divisions as shown in Fig. 1.

For the purpose of achieving both wastewater treatment and power generation, CWs are supplied with two electrodes one represents cathode and other as an anode, made from conductive material for instance graphite or steel [19].

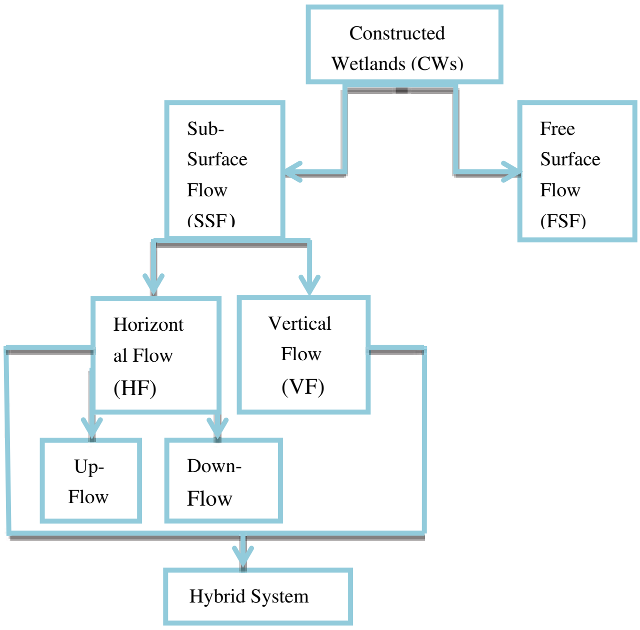

Fig. 1. Types of constructed wetlands by flow regime.

Abbas et al. [20] studied the bioremediation and electricity generation by using open and closed SMFCs [20], whilst treating marine sediments polluted with heavy metals (Cr, Cu and Ni) with a removal efficiency of 80.70%, 72.72% and 80.37% for aerated SMFC and 67.36%, 59.36% and 52.74% for non-aerated SMFC, respectively [21]. Other studies reviewed targets the prototype, operating factors, working mechanisms, applications, and future perspectives of SMFCs [22]. However, arsenic, cadmium and lead removal were observed in a study with aerated SMFC at pH 7.0 were (77.70%, 90.86%, and 83.91%), respectively, with open-circuit voltages was about 665 mV, with quite steady performances for 120 d [23].

This article reviews different types of aquatic plants within vertical down subsurface flow CW with the support of two electrodes in order to generate energy and limit wastewater pollutants.

2. Materials and methods

2.1. CW preparation

Five aquariums with dimensions of (35 cm × 52 cm × 28 cm) were filled with 6 cm graded gravel and 8 cm red sand. The sand has been sieved with dimensions of 2 mm and washed with distilled water to get rid of any crystal or dissolved salts. These aquariums were all exposed to the atmosphere and supplied with an effluent nozzle at the 1.5 cm from the bottom as shown in Fig. 2.

2.2. Plants preparation

Five types of native plants were prepared and transplanted into aquariums separately. The first aquarium is planted with *Juncus*, second with *Schoenoplectus triqueter*, third with *Phragmites australis*, fourth with *Typha latifolia*, and

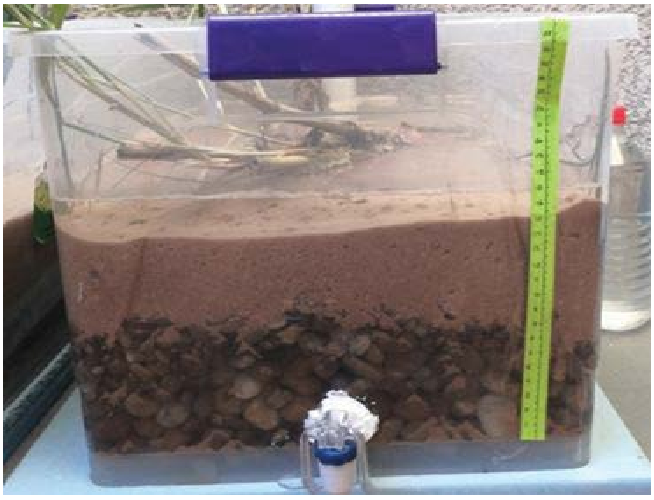

Fig. 2. One sample of SMFC.

fifth with *Cyperus alternifolius*. All of these plants are native plant species; they are tolerant of the aquatic environment and live in ponds or marshes.

Juncus and *Schoenoplectus* were taken from the Tigris River near Al-Khalis district in Dhyala. Whereas *Phragmites australis* was taken from the Tigris River in Baghdad. *C. alternifolius* and *T. latifolia* were collected from a pond of Public Park in Baghdad City. The roots of all plants were washed and planted in the sand. Plants are illustrated in Fig. 3.

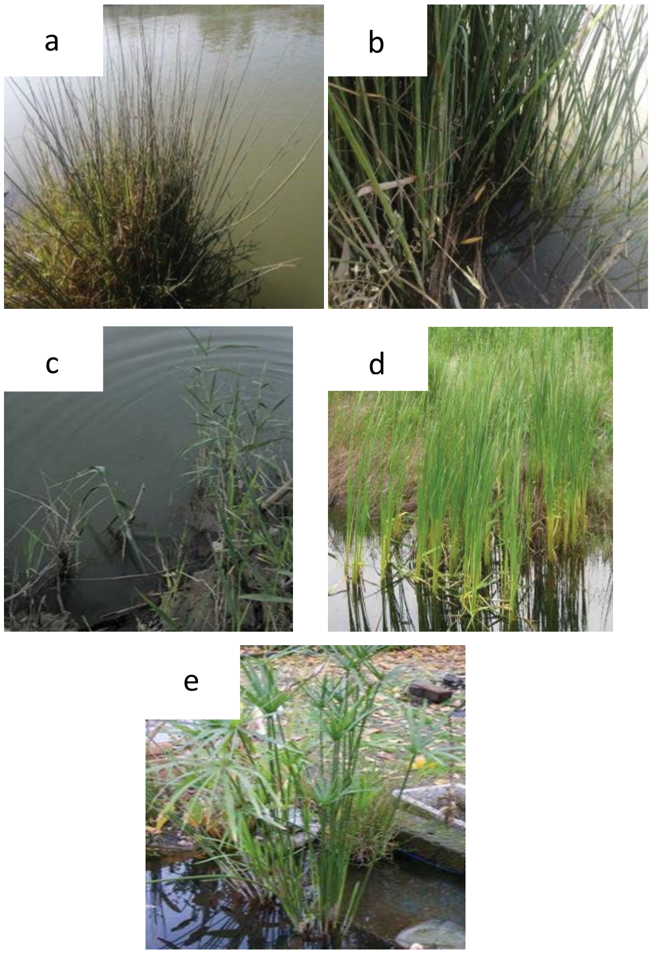

Fig. 3. Different types of Iraqi common aquatic plants. (a) *Juncus*, (b) *S. triqueter*, (c) *P. australis*, (d) *T. latifolia*; and (e) *C. alternifolius*

2.3. Electrodes preparation

As electrodes are essential for completing the electrical circuits, two electrodes, made from graphite with a surface area of 110 cm^2 were used. They have been pretreated and soaked in distilled water for 24 h. Pretreated electrodes can provide microbes adhesion and propagation, consequently enhancing the performance of the reactor [24]. After that, they have been connected with insulated copper wire. The other end of the electrode is soldered with an alligator clip. Solder has been used to avoid any losses or corrosion in copper wire as shown in Fig. 4. Alligator clip helps to hold the external resistor of 220 Ω and facilitates the process of measuring current and voltage of fuel cell using the multi-meter. Hence, the other electrodes in this study were prepared the same as the above manner.

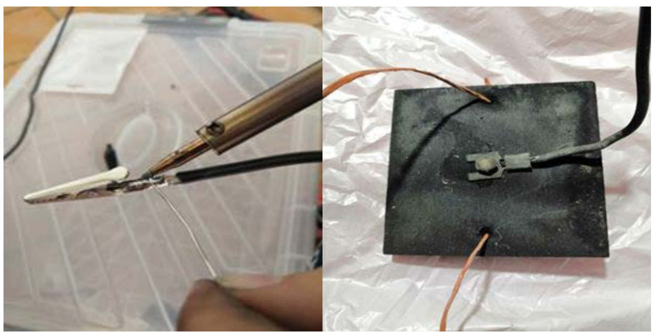

Fig. 4. Electrodes preparations.

2.4. CW and SMFC as one system

In the setup of the experiment, the anode was buried in the deepest point of sediment; to avoid any exposure to the oxygen [25] while the cathode was placed in the sand, between sand-air interface. Wastewater level was maintained to be within the surface of the sand layer to obtain sub-surface flow.

2.5. Laboratory analysis

The used wastewater was real wastewater, collected from the influent basin of crude wastewater in Al-Rustumiya Wastewater Treatment Plant. The chemical characteristics of total dissolved solids (TDS) (mg/L), total suspended solids (TSS) (mg/L), NO_3 (mg/L), PO_4 (mg/L), chemical oxygen demand (COD) (mg/L), Pb (mg/L), Cu (mg/L), and Cd (mg/L) of wastewater were 1,370 ± 20, 25 ± 3, 21 ± 5, 2.4 ± 0.1, 105 ± 3, 0.07 ± 0.01, 0.04 ± 0.02, and 0.02 ± 0.01, respectively. Chemical concentration seems not high as wastewater flows from networks that are mixed with rainfall, runoff, and domestic wastewater. Meanwhile, the physical characteristics of temperature (°C), pH, and electric conductivity

(EC) (µS/cm) were 24.3 ± 4, 7.9 ± 0.02, and 1,995 ± 13, respectively. Wastewater is poured vertically and distributed on all sand area. Wastewater characteristics are summarized in Table 1. However, all experiments were performed in triplicate, all data are expressed as the mean ± standard deviation.

3. Results and discussion

3.1. SMFC as the energy source

The experiment was run for 10 d for energy generation. As seen in Table 1. Data has been taken at two different times per day, at 1 am and 1 pm. These periods have been taken as SMFCs yield different readings at day and night, as long as a microbial fuel cell is exposed and is affected by the solar light. Current and voltage were measured by auto range multi-meter.

Not enough reports are available on the performance of photosynthetic behavior for a system. This explains the fluctuation in output voltages as the system is affected by different factors like electrode materials, plant growth, and other operating parameters [26]. Hence, it is difficult to compare a system based upon only photosynthetic pathways and no clear view if the output voltage is maximized due to the photosynthesis process or microorganisms aggregations. Figs. 5 and 6 show the output voltage during day and night. The voltage at 1 pm is higher than 1 am, it is obviously reasonable as the photosynthesis happens with the presence of solar radiation. Other causes are related such as the physiology of the plant, atmospheric temperature, number of microorganisms within the sediment, etc.

Current and voltage are limited by oxygen loss in the anodic region. In other words, redox conditions are affecting the voltage difference that exists between (anode & cathode). This occurs due to the (gradient) gradience in oxygen concentration between the two compartments. Furthermore, plants that have a high root biomass system were recommended for PMFCs.

In plant science, mechanisms of rhizodeposition have been explored over many decades. Now, is the time for all researchers to apply it for the system performance maximization of SMFCs [27]. Total solids in wastewater affect the transfer of electrons. Highest TSS means the highest electric conductivity and more electrons transfer to produce more voltages [28]. At the beginning of the experiment, TDS was recorded to be 1,370 ± 20 mg/L and EC of 1,995 ± 13 µS/cm. After the first sampling test, TDS and EC increased to a range of (1,730–1,991) mg/L and (3,000–3,900) µS/cm. However, voltage decreased to minimum approximate values of 4 ± 0.4, 2 ± 1.2, 4 ± 3.1, 1 ± 0.3, 1 ± 4 mV for *Juncus*, *S. triqueter*, *P. australis*, *T. latifolia*, and *C. alternifolius*, respectively, as a reason of leakage in microbial community and no source for electrons to transfer due to a limited metabolic process.

In conclusion, all five species showed the same manner in voltage fluctuation during the suction of wastewater for laboratory purposes. They were dramatically increased until

Table 1
Initial concentration of the crude wastewater from Al-Rustumiya Wastewater Treatment Plant

Ph	7.9 ± 0.02
EC (µS/cm)	1,995 ± 13
Temperature (°C)	24.3 ± 4
TDS (mg/L)	1,370 ± 20
TSS (mg/L)	25 ± 3
NO_3 (mg/L)	21 ± 5
PO_4 (mg/L)	2.4 ± 0.1
COD (mg/L)	105 ± 3
Pb (mg/L)	0.07 ± 0.01
Cu (mg/L)	0.04 ± 0.02
Cd (mg/L)	0.02 ± 0.01

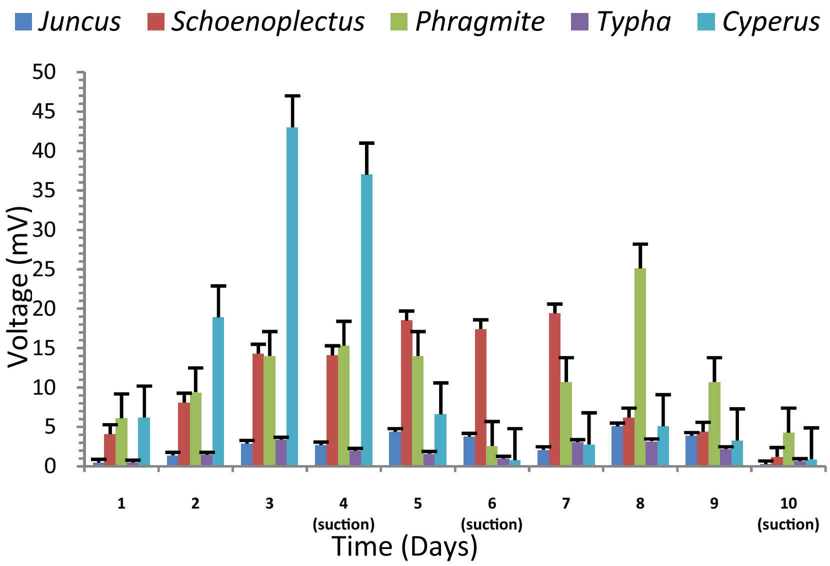

Fig. 5. Voltage per day changes according to plant species at 1 am.

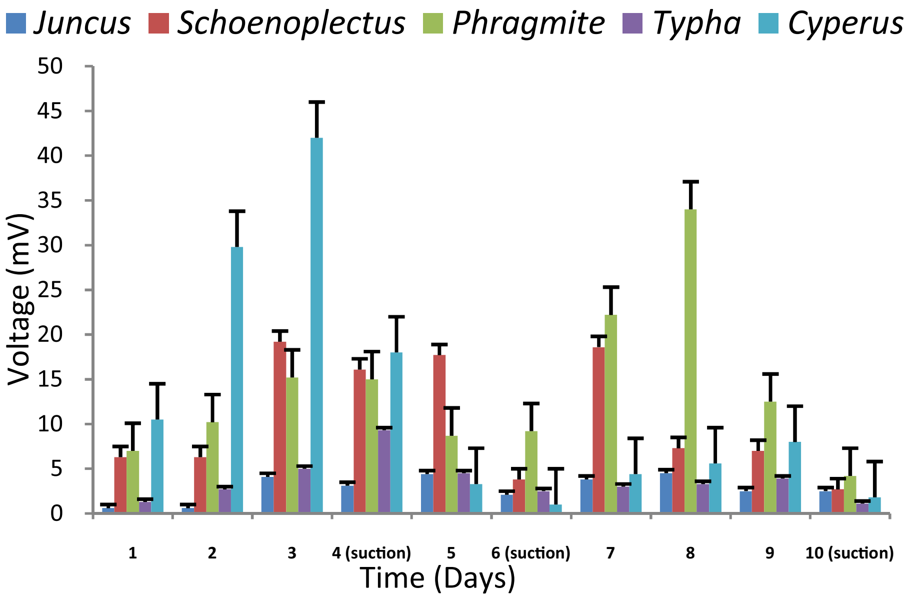

Fig. 6. Voltage per day changes according to plant species at 1 pm.

wastewater suction time has come. However, to gain a clear picture of our results, overall voltage during both periods for *C. alternifolius* is the best in most cases. It recorded the highest voltage in comparison to pm and am and reached to 43 ± 4 mV. Whereas *Juncus* and *T. latifolia* had the lowest voltage outputs among the others. *Juncus* recorded the highest voltage of 5 ± 0.4 mV during (pm) night periods, followed by *T. latifolia*, hit the highest trend which reached 9 ± 0.3 mV. A stable system requires longevity and vitality of plants that cope with harsh environmental conditions.

3.2. SMFC as the wastewater treatment system

The study of SMFC as a wastewater treatment unit is still limited due to a few reports and experiments [29]. Factors that affect the efficiency of wastewater treatment are the roots of wetland plants, microorganisms near rhizosphere, configurations, and electrode material. In this work, the Spectrophotometer was used for analyzing the amount of NO_3 and PO_4.

3.2.1. Heavy metals removal

Soluble metals can enter into the root simplest by crossing the plasma membrane of the root endodermal cells, or they can enter the root apoplast through space between cells. While it is possible for liquids to travel up through the plant by apoplastic flow through the vasculature of the plant. The cell types where the metals are deposited vary between hyper-accumulator species [30]. Initial concentration for Pb, Cu, and Cd was 0.07 ± 0.01, 0.04 ± 0.02, and 0.02 ± 0.01 mg/L, respectively, were removed to be not recognized by the testing device from the first sampling process. Whatever the case, phytoremediation of Pb, Cu, and Cd increased when the number of plants and time for taking samples was increased.

3.2.2. COD removal

Variant time periods showing significant differences in the concentration of COD. Fig. 7 shows the removal efficiency percentage of COD by five common plants with respect to 10 d. Samples test was done at the beginning of the experiment, day 4, day 7, and the final stage of the experiment. As noticed from the figure, percentages removals of turbid water are varying with respect to plant types.

For *Cyperus* the COD value decreased from 105 to 29 ppm, where the percentage removal was 72.3%. For *T. latifolia* the COD decreased from 105 ± 3 to 10 ± 0.8 ppm, where the percentage removal was 90.4%. For *P. australis* the COD decreased from 105 ± 3 to 14 ± 0.6 ppm, where the percentage removal was 86.6%. For *S. triqueter* the COD decreased from 105 ± 3 to 9 ± 0.2 ppm, where the percentage removal was 91.4%. %. For *C. alternifolius* the COD decreased from 105 ± 3 to 28 ± 4 ppm, where the percentage removal was 73.3%. Therefore, systems provided effective COD treatment with greater than 90% COD removal.

3.2.3. NO_3 removal

Nitrate concentrations are included as an1indicator of how much nitrogen has been removed by each plant in a CW system. As shown in Fig. 8, *Cyperus*, *P. australis*, *T. latifolia*, and *S. triqueter* recorded a very accurate and high removal efficiency ranged between 80%–82% whilst *Juncus* was the lowest percentage removal of 66.6% at the end of the run. Initial NO_3 was 21 ± 5 ppm. It can be reduced effectively by *P. australis* and *T. latifolia* to 4 ± 0.2 ppm with a percentage removal of 80.9%.

3.2.4. PO_4 removal

Phosphorus in wetlands happens mainly as phosphate in organic and inorganic compounds. Phosphate can be

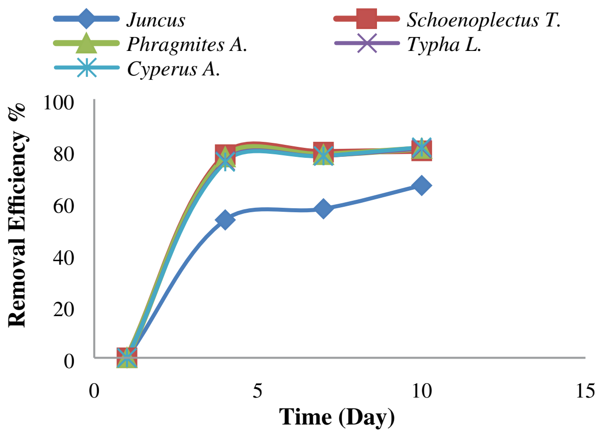

Fig. 7. COD removal efficiency according to plant species for 10 d.

uptaken by plants and converted to tissue phosphorus or may be absorbed into wetland soil and sediment [31]. The aquatic plant *P. australis* is found to be the most effective plant species for the phytoremediation process of phosphorus compared to the removal efficiencies of *T. latifolia*, *C. alternifolius*, *Juncus*, and *S. triqueter* species of 62.5%, 66.6%, 58.3%, and 66.6%, respectively, after an initial dose of 2.4 ± 0.1 ppm of crude wastewater as shown in Fig. 9.

3.2.5. TSS removal

TSS removal has occurred due to several factors. One of the most important factors is the presence of gravel in CW that would increase the performance. The basic reason for such good performance of the gravel beds was the better physical/mechanical structure of the substrate as TSS removal is removed mainly through physical processes [32]. Besides, the density of the root system is an essential factor that is able to make a simple sand/gravel filter into a stronger compacted filter with a trapping phase for suspending solids. Fig. 10 illustrates how TSS removal efficiencies were different from one plant to another.

3.2.6. pH

pH affects the biological activities occurring during the treatment of wetlands and potentially influences the efficiency of nutrient removal. On the other hand, the nitrifying bacteria are very sensitive to pH. Thus, an increase in pH to greater than 9 may reduce the occurrence of the nitrification process. However, plants thrive with a pH of 5.5 to 6.5.

The pH stabilized in the range of 7–8 in all five aquariums during the treatment process, which is the optimum range for purification purposes. *S. triqueter* and *P. australis* have similar behavior in reducing pH to 7 ± 0.01 and 6.9 ± 0.05, respectively. *Juncus* showed a minimum reduction in pH reaching 7.3 ± 0.02 only. But *C. alternifolius* outperformed the others by reaching to a maximum pH reduction toward acidity to 6.7 ± 0.08 on the pH scale. However, the plant seemed to be an alkaline aquatic plant as long as it survives until the end of the experiment. *T. latifolia* remained

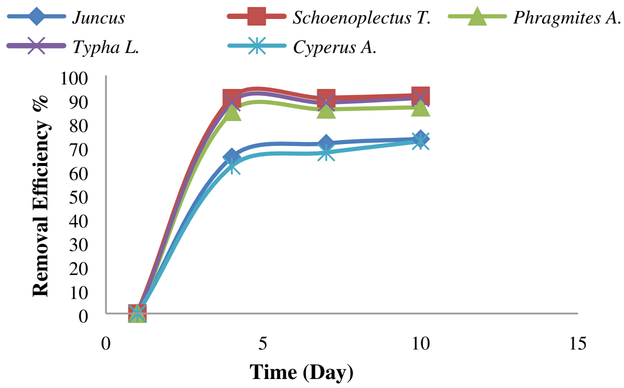

Fig. 8. NO_3 removal efficiency according to plant species for 10 d.

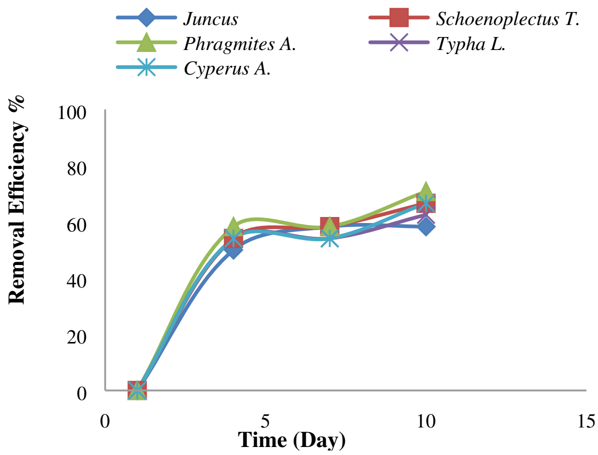

Fig. 9. PO_4 removal efficiency according to plant species for 10 d.

at the same pH level by the end of two periods of sampling demonstrated in Fig. 11.

4. Conclusions

This paper explains the status of SMFCs as an alternative technology and a solution to the energy crisis and water. SMFC is considered as a means to generate electricity from organic compounds, at the same time it is capable of lowering the concentration of contaminants in wastewater. SMFCs challenge ahead on how to upgrade the process' efficiency and minimize investment costs. The major conclusions deduced during the study are summarized as follows:

- This paper revealed the successful performance of the vertical flow constructed wetland for the treatment of crude wastewater with respect to TSS, NO_3, PO_4, Cd, Cu, Pb and pH.
- Treatment process and electricity production is influenced by temperature, type of plant, microbial assemblages, and day's periods.
- Locally available plants used in the small-scale model, *C. alternifolius* and *P. australis*, showed prominent growth and such a quick survival within the CW beds.

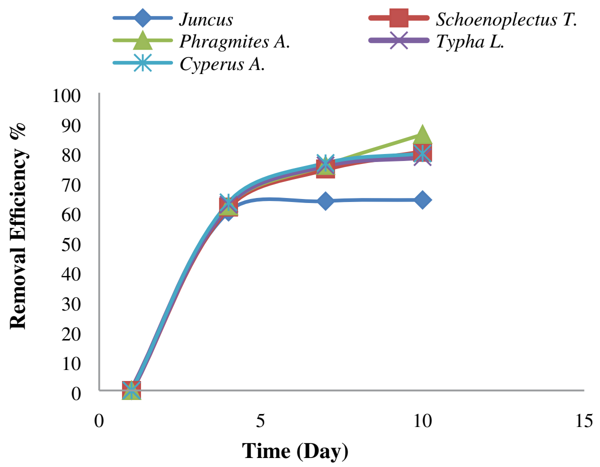

Fig. 10. TSS removal efficiency according to plant species for 10 d.

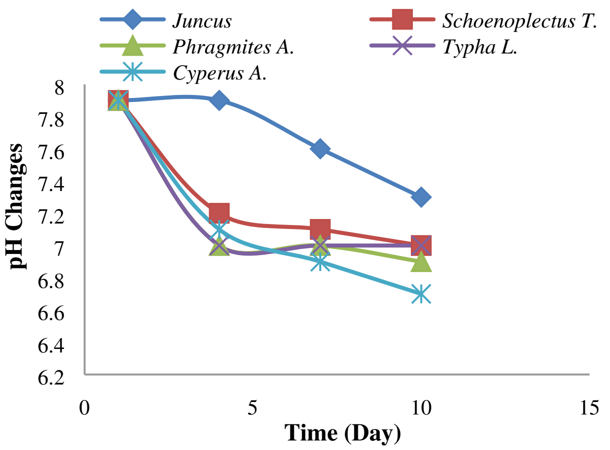

Fig. 11. pH changes according to plant species for 10 d.

- COD removal efficiencies were grossly promising and stable in the treatment.
- CW design is being complexed and has various forms. Regional-specific design according to the country it's constructed is an essential step for upcoming CWs.

The need for collaboration and interdisciplinary research in order for PMFCs can be applied in Iraq as one of the most alternative procreators of renewable energy technologies. Research on SMFC in Iraq is still quite rare. Therefore, there is a (quite) chance in finding the optimal configuration and adapting this technology to Iraq's environment.

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References

[1] R.A. Timmers, D.P.B.T.B. Strik, H.V.M. Hamelers, C.J.N. Buisman, Long-term performance of a plant microbial fuel cell with *Spartina anglica*, Appl. Microbiol. Biotechnol., 86 (2010) 973–981.

[2] M. Helder, W.-S. Chen, E.J.M. van der Harst, D.P.B.T.B. Strik, H.B.V.M. Hamelers, C.J.N. Buisman, J. Potting, Electricity production with living plants on a green roof: environmental performance of the plant-microbial fuel cell, Biofuels, Bioprod. Biorefin., 7 (2013) 52–64.

[3] J. Vymazal, Removal of nutrients in various types of constructed wetlands, Sci. Total Environ., 380 (2007) 48–65.

[4] US EPA, Manual Constructed Wetlands Treatment of Municipal Wastewaters, US Environmental Protection Agency, National R., Cincinnati, Ohio, 2000.

[5] B. Erable, N.M. Duțeanu, M.M. Ghangrekar, C. Dumas, K. Scott, Application of electro-active biofilms, Biofouling, 26 (2010) 57–71.

[6] Z. Fang, H.-L. Song, N. Cang, X.-N. Li, Electricity production from Azo dye wastewater using a microbial fuel cell coupled constructed wetland operating under different operating conditions, Biosens. Bioelectron., 68 (2015) 135–141.

[7] J.B. Williams, Phytoremediation in wetland ecosystems: progress, problems, and potential, Crit. Rev. Plant Sci., 21 (2002) 607–635

[8] S.D. Wallace, R.L. Knight, Small-Scale Constructed Wetland Treatment Systems: Feasibility, Design Criteria and O&M Requirements, Water Environment Research Foundation (WERF), Alexandria, 2006.

[9] J. García, D.P.L. Rousseau, J. Morató, E. Lesage, V. Matamoros, J.M. Bayona, Contaminant removal processes in subsurface-flow constructed wetlands: a review, Crit. Rev. Env. Sci. Technol., 40 (2010) 561–661.

[10] A.K. Kivaisi, The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review, Ecol. Eng., 16 (2001) 545–560.

[11] J. Vymazal, Constructed wetlands for wastewater treatment: five decades of experience, Environ. Sci. Technol., 45 (2011) 61–69.

[12] S.E. Mbuligwe, Comparative treatment of dye-rich wastewater in engineered wetland systems (EWSs) vegetated with different plants, Water Res., 39 (2005) 271–280.

[13] M. Borin, D. Tocchetto, Five year water and nitrogen balance for a constructed surface flow wetland treating agricultural drainage waters, Sci. Total Environ., 380 (2007) 38–47.

[14] D. Istenič, C.A. Arias, J. Vollertsen, A.H. Nielsen, T. Wium-Andersen, T. Hvitved-Jacobsen, H. Brix, Improved urban stormwater treatment and pollutant removal pathways in amended wet detention ponds, J. Environ. Sci. Health. Part A Toxic/Hazard. Subst. Environ. Eng., 47 (2012) 1466–1477.

[15] C.E. Reimers, L.M. Tender, S. Fertig, W. Wang, Harvesting energy from the marine sediment–water interface, Environ. Sci. Technol., 35 (2001) 192–195.

[16] L.M. Tender, C.E. Reimers, H.A. Stecher, D.E. Holmes, D.R. Bond, D.A. Lowy, K. Pilobello, S.J. Fertig, D.R. Lovley, Harnessing microbially generated power on the seafloor, Nat. Biotechnol., 20 (2002) 821–825.

[17] W.C. Allen, P.B. Hook, J.A. Biederman, O.R. Stein, Temperature and wetland plant species effects on wastewater treatment and root zone oxidation, J. Environ. Qual., 31 (2002) 1010–1016.

[18] Y. Yang, Y.Q. Zhao, S.P. Wang, X.C. Guo, Y.X. Ren, L. Wang, X.C. Wang, A promising approach of reject water treatment using a tidal flow constructed wetland system employing alum sludge as main substrate, Water Sci. Technol., 63 (2011) 2367–2373.

[19] X. Li, Microbial fuel cell-constructed wetland coupling system for sewage treatment and electrical performance, Water Treat. Technol., 85 (2018) 2.

[20] S.Z. Abbas, M. Rafatullah, M.A. Khan, M.R. Siddiqui, Bioremediation and electricity generation by using open and closed sediment microbial fuel cells, Front. Microbiol., 9 (2019) 3348, doi: 10.3389/fmicb.2018.03348.

[21] S.Z. Abbas, M. Rafatullah, N. Ismail, F.R. Shakoori, Electrochemistry and microbiology of microbial fuel cells treating marine sediments polluted with heavy metals, RSC Adv., 8 (2018) 18800–18813.

[22] S.Z. Abbas, M. Rafatullah, N. Ismail, M.I. Syakir, A review on sediment microbial fuel cells as a new source of sustainable energy and heavy metal remediation: mechanisms and future prospective, Int. J. Energy Res., 41 (2017) 1242–1264.
[23] S.Z. Abbas, M. Rafatullah, N. Ismail, R.A. Nastro, Enhanced bioremediation of toxic metals and harvesting electricity through sediment microbial fuel cell, Int. J. Energy Res., 41 (2017) 2345–2355.
[24] C.-T. Wang, T. Sangeetha, W.-M. Yan, W.-T. Chong, L.-H. Saw, F. Zhao, C.-T. Chang, C.-H. Wang, Application of interface material and effects of oxygen gradient on the performance of single-chamber sediment microbial fuel cells (SSMFCs), J. Environ. Sci., 75 (2019) 163–168.
[25] J.Y. An, B.K. Kim, J.H. Nam, H.Y. Ng, I.S. Chang, Comparison in performance of sediment microbial fuel cells according to depth of embedded anode, Bioresour. Technol., 127 (2013) 138–142.
[26] N. Ueoka, N. Sese, M. Sue, A. Kouzuma, K. Watanabe, Sizes of anode and cathode affect electricity generation in rice paddy-field microbial fuel cells, J. Sustainable Bioenergy Syst., 6 (2016) 10–15, doi: 10.4236/jsbs.2016.61002.
[27] H.P. Bais, T.L. Weir, L.G. Perry, S. Gilroy, J.M. Vivanco, The role of root exudates in rhizosphere interactions with plants and other organisms, Ann. Rev. Plant Biol., 57 (2006) 233–266.
[28] M. Helder, D.P.B.T.B. Strik, H.V.M. Hamelers, A.J. Kuhn, C. Blok, C.J.N. Buisman, Concurrent bio-electricity and biomass production in three plant-microbial fuel cells using *Spartina anglica*, *Arundinella anomala* and *Arundo donax*, Bioresour. Technol., 101 (2010) 3541–3547.
[29] S.B. Wu, T. Lv, Q.M. Lu, Z. Ajmal, R. Dong, Treatment of anaerobic digestate supernatant in microbial fuel cell coupled constructed wetlands: evaluation of nitrogen removal, electricity generation, and bacterial community response, Sci. Total Environ., 580 (2017) 339–346.
[30] W.A. Peer, I.R. Baxter, E.L. Richards, J.L. Freeman, A.S. Murphy, Phytoremediation and Hyper Accumulator Plants, The University of Chicago, The Science Behind Genetically Modified Organisms, 2005, pp. 43.
[31] S. Saumya, S. Akansha, J. Rinaldo, M.A. Jayasri, K. Suthindhiran, Construction and evaluation of prototype subsurface flow wetland planted with *Heliconia angusta* for the treatment of synthetic greywater, J. Cleaner Prod., 91 (2015) 235–240.
[32] H. Brix, C.A. Arias, The use of vertical flow constructed wetlands for on-site treatment of domestic wastewater: New Danish guidelines, Ecol. Eng., 25 (2005) 491–500.