Desalination and Water Treatment
www.deswater.com

doi:10.5004/dwt.2018.22744

120 (2018) 180–184
July

Textile wastewater treatment by using cement kiln dust and biochar filters

Esawy Kasem Mahmoud

Department of Soil and Water Science, Faculty of Agriculture, Tanta University, P.O. Box 31527 Tanta Egypt, Tel. +20 403455584, Fax +20 403455570, email: esawy.rezk@agr.tanta.edu.eg (K.M. Esawy)

Received 2 December 2017; Accepted 30 June 2018

ABSTRACT

The efficacy of biochar and cement kiln dust as alternative low-cost adsorbents for the removal of organic and inorganic pollutants from textile wastewater was investigated. Studies were carried out to test the column filter to assess the effects of hydraulic loading and organic concentration on the efficiency of CKD and CKD + Biochar filters to remove heavy metals, colour and COD from textile wastewater. The results reveal that the use of hydraulic loading at 1.0 $m^3\ m^{-2}\cdot h^{-1}$ resulted in a similar removal efficiency of COD and colour as the hydraulic loading at 2.0 $m^3\ m^{-2}\cdot h^{-1}$. COD and colour removal increased with the increasing their concentrations for the used CKD + Biochar filter. Seed germination of treated water by CKD + Bio filter was higher than CKD filter. Treated effluents by the CKD + biochar filter are within the acceptable range of irrigation in salinity, pH, phosphorus and heavy metal concentrations. CKD + biochar filter are good quality treated wastewater to remove color, heavy metals and COD concentrations. Thus, CKD + Biochar filter can be used as a low-cost adsorbent and a simple technology for the removal of organic and inorganic pollutants from textile wastewater.

Keywords: Biochar; Cement kiln dust; Textile wastewater; Low-cost adsorbents; Irrigation

1. Introduction

The textile industry is one of the largest consumers of water (800–1000 $m^3\ ton^{-1}$) and liquid sewage generators [1]. Liquid waste from these industries is complex, containing a wide variety of products, such as dyes, detergents, humectants, oxidants. And also, are highly toxic and carcinogenic to flora and fauna as well as humans [2]. In the recent decade, wastewater that is discharged by dye manufacturing and textile industries has become an environmental concern. In many countries legal requirements for the discharge of contaminated wastewater are strengthened [3]. The effluents of textile industries are not bound by Law No. 4/1994 (Egyptian Standards regulating the discharge of industrial waste waters to the sewerage network). This is due to high pH of the final effluent and their high organic loads. Therefore, the treatment of these industrial effluents is necessary before their final discharge into the environment. Conventional methods used in textile wastewater treatment such as biological processes, chemical coagulation and activated carbon adsorption were expensive and disposal problems [4]. Biological processes are environmentally friendly microbial removal, detoxification and more cost-effective. However, the biodegradable liquid waste is slowly biodegradable and has high toxicity and colour [5]. Feng et al. [6] showed that hybrid adsorption–periphyton reactor was a novel, environmentally friendly, efficient and promising dye-purification method. Among the various water and wastewater treatment technologies, adsorption is best because of low cost, simple design and easy operation. Activated carbon is usually used to remove various types of contaminants from wastewater, but it is higher costs. Therefore, attempts are being made to develop low-cost adsorbents from industrial and agricultural waste materials [7]. In addition, carbonated organic waste can generate a range of new products that can replace existing products that have high carbon effects such as activated carbon used in adsorption. Sorption of pollutants from wastewater to biochar is attributed to the high surface area and porosity [8]. While most studies on the application of biochar concentrate on soil amendment, there has been increasing interest

*Corresponding author.

1944-3994 / 1944-3986

in the use of biochar to treat wastewater. Some studies have shown that biochar can be an effective absorbent to absorb heavy metals from wastewater [9,10]. Rio et al. [11] found that the filtration could effectively reduce dyes and phenol when used sludge char and limed sludge chars as media. Fan et al. [12] found that a mixed sludge and tea waste char could effectively adsorb some contaminants such as methylene blue. Egypt has 22 cement factories producing about 46 million metric ton year^{-1} [13]. Recently, the use of CKD as adsorbents in wastewater treatment has a great interest to effectively remove mineral contaminants from industrial wastewater [14]. CKD + Coal filter has been used as a simple technology and a low-cost, effective treatment of textile industrial effluents [15]. However, only a few researchers have investigated the possibility of using biochar and CKD as a low-cost technology to treat textile wastewater.

The objective of this study was to evaluate the efficiency of cement kiln dust and biochar filters on colour, BOD, COD, heavy metals and seed germination test of textile wastewater.

2. Materials and methods

2.1. Adsorbent cement kiln dust and biochar

The biochar (Bio) used in this experiment was made of rice straw from a local producer using a batch pyrolysis facility at a final temperature (400°C) with 2 h retention time. Biochar samples were ground and sieved < 0.5 mm, prior to be used and characterized. It is found that biochar product had high organic carbon by 62.5%. Biochar characterized by electrical conductivity (EC) of 2.45 dS m^{-1} (1 biochar: 10 water), pH 8.2, total N 1.38%, total P 0.65%, total K 1.18% and cation exchange capacity (CEC) of 80.56 c mol kg^{-1} biochar. CKD and biochar were used without any pretreatment (particle size < 1 mm). CKD is obtained from El-Amerya of cement plants. X-ray analysis of cement kiln dust (CKD) showed that it was an alkaline waste material and its main components were calcium carbonate of 47.6%; oxides of aluminum of 4.2%; iron of 2.8% and magnesium of 2.3%; free lime of 4.8% and some alkali salts such as sodium and potassium. Its specific gravity was 2.92 and specific surface area 4440 cm^2 g^{-1}.

2.2. Column filter experiment

In this study, cement kiln dust (CKD) and CKD + Biochar (with 1: 1 V/V) are used to examine the removal of organic and inorganic pollutants from textile wastewater. Cement kiln dust and CKD + Biochar filters were tested in a 16 week long column filter experiment. Column filter was made from PVC (7.62 cm diameter and 140 cm long) filled with 100 cm CKD or (CKD + Biochar). On top and at the bottom of the materials, a layer of 10 cm washed, crushed stones (0.1 cm in diameter) were filled in order to enhance influent distribution and drainage. A hydraulic loading rate as m^3 m^{-2} h^{-1} was adjusted by using a peristaltic pump. Two hydraulic loading rates (HL) of 1.0 and 2.0 m^3 m^{-2} h^{-1} were used to study the effects of hydraulic loading rate on the efficiency of CKD and CKD + Biochar filters for treating textile wastewater. The analytical procedures, including BOD, COD, colour, EC, pH and heavy metals were performed as described in the Standard Methods for the Examination of Water and Wastewater [16]. Germination test was measured in triplicate using cress (*Lepidium sativum*) as described by Mathur et al. [17]. Tissue paper layers of 2 cm thickness were put in petri dishes with 20 cress seed, covered with tissue paper, and then soaked to treat and raw textile wastewater saturation for the percent germination.

2.3. Statistical analysis

The data of effect of hydraulic loading on filter efficiency of CKD + Biochar to remove colour and COD of textile wastewater were analyzed statistically using SAS software. Duncan's multiple range tests were used to compare the means of the treatments. Statistical significance level of $P < 0.05$ was used.

3. Results and discussion

3.1. Characteristics of textile wastewater

Table 1 shows the characteristics of textile wastewater from Al-Nasr Spinning & Weaving Company. Total dissolved solids (TDS) for wastewater ranged from 2290 to 2654 mg l^{-1}, and when used in irrigation, soil salinity increases. The textile wastewater was highly alkaline (pH 10.0–11.4). This may be due to use of sodium carbonate, sodium hydroxide and salts which are used in the different processes of textile industry. Wastewater of other textile and dye industry showed a similar pH trend, as found in the present study, being highly alkaline in nature [18]. Concentrations of BOD and COD-ranged from 329 and 652 to 552 and 1650 mg l^{-1} respectively, which would classify the wastewater as high strength [19]. A high COD level means toxic and non-biodegradable substances [18]. In this study, the calculated BOD to COD ratio was ranged from 0.26 to 0.65. The wastewater is considered to be easily treatable by biological means if the BOD to COD ratio is 0.5 or greater ratio. While, if the ratio is below 0.5, indicating their some toxic substances and non-biodegradable nature [19,20]. Colour of textile wastewater turbidity was ranged from 401 to 1710 PCU. Colour may be caused by dyes and other inorganic substances and also caused by a wide variety of colloidal substances.

3.2. Effect of hydraulic loading on filter efficiency of CKD + Biochar to remove colour and COD of textile wastewater

Table 2 presents the effects of hydraulic loading on the efficiency of the CKD + Biochar (CKD + Bio) filter for COD and colour removal from textile wastewater. The results reveal that the use of hydraulic loading at 1.0 m^3 m^{-2}·h^{-1} resulted in a similar removal efficiency of COD and colour as the hydraulic loading at 2.0 m^3 m^{-2}·h^{-1}. The removal efficiency of colour and COD in hydraulic loading at 1.0 m^3 m^{-2}·h^{-1} ranged from 94.4% and 73.1% to 99.3% and 89.6%, respectively. Difference in colour and COD between hydraulic at 2.0 m^3 m^{-2}·h^{-1} and 1.0 m^3 m^{-2}·h^{-1} are not statistically significant. During filtration, the removal of the suspended solids, colour and COD are accomplished by a complex process involving one or more mechanisms such as straining, sedimentation, interception, impaction, and an

Table 1
Characteristics of textile wastewater

Date of samples	pH	TDS	Colour, PCU	COD, mg l^{-1}	BOD, mg l^{-1}	BOD/COD
10/12/2015	10.0	2365	1710	1368	552	0.40
17/12/2015	11.0	2320	1310	1331	430	0.32
7/1/2016	11.0	2654	620	1650	433	0.26
4/2/2016	10.3	2290	770	1349	432	0.32
18/2/2016	11.2	2352	401	652	422	0.65
25/2/2016	11.1	2298	1220	1179	432	0.37
10/3/2016	11.4	2355	1010	892	329	0.37
31/3/2016	10.6	2364	1230	1360	544	0.4
Range	10.0–11,4	2290–2654	401–1710	652–1650	329–552	0.26–0.65

Table 2
Effects of hydraulic loading on the efficiency of CKD+Biochar filter for COD and colour removal of textile wastewater. Different letters indicate significant difference ($p < 0.05$) between each treatment

Samples	Date	Hydraulic loading rate at 1.0 m^3 $m^{-2}{\cdot}h^{-1}$		Hydraulic loading rate at 2.0 m^3 $m^{-2}{\cdot}h^{-1}$	
		COD mg L^{-1}	Colour PCU	COD mg L^{-1}	Colour PCU
Raw	10/12/2015	1368b	1710a	1368b	1710a
Treated		202g	3.7i	229g	3.9I
Removal, %		85.2	97.8	83.3	97.7
Raw	17/12/2015	1331d	1310b	1331d	1310b
Treated		139h	8.9h	142h	10h
Removal, %		89.6	99.3	89.3	99.2
Raw	7/1/2016	1650a	620d	1650a	620d
Treated		444e	10h	473.e	12h
Removal, %		73.1	98.4	71.3	98
Raw	4/2/2016	1349c	770c	1349c	770c
Treated		362f	42g	381f	61g
Removal, %		73.2	94.5	71.8	92

adsorption [21]. The COD adsorption mechanism is complicated and, although the attraction is primarily physical, is a combination of physical, chemical, and electrostatic interactions between the CKD + Bio and the organic compounds. Adsorption of organics by precipitation is the more dominant mechanism at higher pH [22].

3.3. *Effect of organic concentration on filter efficiency of CKD + Biochar to remove colour and COD of textile wastewater*

Results showed that the COD and colour removal increased with the increasing their concentrations in textile wastewater for the used CKD + Bio filter at hydraulic loading 2.0 m^3 $m^{-2}{\cdot}h^{-1}$ (Table 3). CKD + Bio filter can remove about 93% as an average of colour and 76% of the COD for which the colours and COD are less than 500 PCU and 650 mg l^{-1}, respectively. With the increased colour and COD concentrations in raw sewage increased the efficiency of the CKD+Bio filter which reached removal to about 92% of colour and 82% of COD. This trend agreed with Atta et al. [23] found that the COD concentration increased the COD removal increased for the three used biofilters

3.4. *Comparison between CKD and (CKD + Bio) filters for treated textile wastewater and it's compared to water criteria for irrigation*

As shown in (Table 4), removal of COD, BOD, heavy metals and colour from textile wastewater by CKD + Bio filter was higher efficiency than CKD filters at hydraulic loading 2.0 m^3 $m^{-2}{\cdot}h^{-1}$. Difference in colour, heavy metals, TDS, BOD and COD between CKD and CKD + Biochar filters are statistically significant. BOD and COD concentrations of treated water by CKD + Biochar filter are higher than in the Egyptian guideline for irrigation. Not worth anything that more than limited values of BOD and COD are in their treated wastewater no adverse effects on growing plants as noted in the rise seed germination (Table 4). Mahmoued [15] showed the ability of CKD to reduce the organic material concentrations and to remove pathogens and suspended solids from raw wastewater. Mixing biochar and CKD in the filter improved the quality of treated water for removing colour and COD (Tables 2,4). These enhancements may be attributed to the high of porosity and a specific surface area of biochar for adsorption of pollutants.

Table 3
Effects of concentrations on the efficiency of CKD+Biochar filter for COD and colour removal of textile wastewater at hydraulic loading rate at 2.0 m^3 m^{-2}·h^{-1}

COD, mg l^{-1}		Removal %	Colour, PCU		Removal %
Raw	Treated		Raw	Treated	
1368	229	83.3	1710	39	97.7
1179	240	79.6	1220	52	95.7
892	162	81.7	1010	44	95.6
652	142	78.2	401	30	92.5
650	163	75.0	500	40	92.0
645	118	81.7	218	26	88.1
482	124	74.0	400	24	94

Table 4
Comparison between CKD filter and CKD+Biochar filter for treated textile wastewater at hydraulic loading rate at 2.0 m^3 m^{-2}·h^{-1}, average = 10 samples

Parameters	Units	Grude sewage	CKD filter	Removal %	CKD+Bio filter	Removal %	Water criteria of irrigation[a]
Colour	PCU	1540	43a	97.2	22[b]	98.6	<200
COD	mg l^{-1}	1760	356a	79.8	233[b]	86.8	60b
BOD	mg l^{-1}	462	155a	66.5	108[b]	76.6	40 b
pH		10.63–11.7	8.04–8.21a	–	8.01–8.06[b]	–	6.5–8.4
TDS	mg l^{-1}	2644	1994a	–	1863[b]	–	2000
PO_4	mg l^{-1}	15.4	0.97a	93.7	0.91[b]	94.1	–
Cd	mg l^{-1}	0.58	0.01a		0.01[a]		0.01
Pb	mg l^{-1}	5.34	0.37a		0.2[b]		5.00
Mn	mg l^{-1}	6.22	0.20a		0.13[b]		0.20
Zn	mg l^{-1}	7.24	0.24a		0.01[b]		2.00
GI	%	16	98[a]		100[a]		–

Water parameters compared to water criteria for irrigation in US. EPA 1993 (a) and Egypt (law 48/1982) (b).

Seed germination of cress (*L. sativum*) was used to obtain the possibility of reuse of treated wastewater in irrigation. Seed germination index (GI) is a good indicator of plant toxicity [24]. Seed germination of treated water by CKD + Biochar filter was higher than CKD filter. These improvements it can be attributed to the adsorption of toxic organic and inorganic compounds in these liquid wastes by CKD and biochar which caused phytotoxicity for growing plants.

Concentration of heavy metals in textile wastewater is extremely high and is not suitable for irrigation (Table 4). After textile wastewater treatment using the CKD + Biochar filter, the effluent water is within the acceptable range of irrigation [25]. Mixed CKD and biochar had been improved effluent quality of textile effluents for removing heavy metals. Inyang et al. [26] found that the main role of Pb(II) adsorption by digested cow dung biochar was surface precipitation. Pb (II) reacted with CO_3^{2-}, HCO_3^-, $H_2PO_4^-$ ions on the surface of biochar forming $PbCO_3$, $Pb(CO_3)_2(OH)_2$ and $Pb_5(PO_4)_3X\{S\}$ (where X may be F^-, Cl^-, Br^-, or OH^-) precipitation. The adsorption mechanisms for heavy metals by biochar involved electrostatic attraction, precipitation on biochar and formation of complexes between metals and functional groups on biochar [27,28]. Heavy metal sorption by biochar was mostly through the formation of surface complexes between these metals and –OH or –COOH groups [29]. Heavy metals reduction by CKD in CKD filter may be attributed to adsorption of heavy metals on $CaCO_3$ existing in CKD and surface metal-complexes formation (interaction of metal with surface sites of oxides [30].

Phosphorus concentration of treated water by CKD + Biochar filter was lower than CKD filter and its within the acceptable range of irrigation [25]. Biochar can act as an effective adsorbent for both organic and inorganic materials in the wastewater. [31]. The adsorption of phosphorus is mainly through the combination electrostatic attraction with the precipitation of the mineral composition. At the same time, because biochar has good adsorption capacity for phosphorus, it can be used as a slow-release fertilizer and has the characteristics of agricultural environment-friendly [31]. At pH values typical for wastewater, i.e. pH 8.5–pH 9.5, the dominating precipitate is calcium phosphate (hydroxyapatite) [32].

Total dissolved solids and pH of treated effluents are within the acceptable range for irrigation [25]. Results indicated that the biochar was capable to ameliorate salinity stress by adsorbing Na^+ due to its high adsorption capacity. Similar effects have been previously noted with activated carbon in the treatment of various industrial waste waters [33].

4. Conclusion

This study showed that the decreasing colour, COD, BOD and heavy metals from textile wastewater and increasing of seed germination for treating effluents CKD + biochar filter at a hydraulic loading rate of 2.0 $m^3\ m^{-2}\cdot h^{-1}$ were higher efficiency than CKD filters. Treated effluents by the CKD + biochar filter are within the acceptable range of irrigation in salinity, pH, phosphorus and heavy metal concentrations. Thus, CKD + biochar filter can be used as a simple technology and a low-cost, effective treatment of textile wastewater.

Acknowledgements

The authors thank the Laboratory of Soil and Water Sciences, Agriculture faculty, Tanta University, Egypt, for their assistance during this work.

References

[1] A. Bes-Piá, J. Mendoza-Roca, M. Alcaina-Miranda, A. Iborra-Clar, M. Iborra-Clar, Reuse of wastewater of the textile industry after its treatment with a combination of physico–chemical treatment and membrane technologies, Desalination, 149 (2002) 169–174.
[2] Y. Fang, D. Dionysiou, Y. Wu, H. Zhou, L. Xue, S. He, L. Zhang, Adsorption of dye stuff from aqueous solutions through oxalic acid-modifed swede rape straw: adsorption process and disposal methodology of depleted bioadsorbents, Biores. Technol., 138 (2013) 191–197.
[3] Z. Wang, M. Xue, K. Huang, Z Liu, Textile dyeing wastewater treatment, Advances in Treating Textile Effluent, Prof. Peter Hauser (Ed.), 2011. In Tech, Available from: http://www.intechopen.com/books/advances-in-treating-textile-effluent/textile-dyeing waste water treatment.
[4] J. Maier, A. Kandelbauer, A. Erlacher, A. Cavaco-Paulo, M.G. Gübitz, A new alkali–thermostable azoreductase from Bacillus sp. Strain SF, Appl. Environ. Microbiol., 70 (2004) 837–844.
[5] F.J. Hai, K. Yamamoto, F. Nakajima, K. Fukushi, Removal of structurally different dyes in submerged membrane fungi reactor – Biosorption/PAC-adsorption, membrane retention and biodegradation, J. Membr. Sci., 325 (2008) 395–403.
[6] Y. Feng, L. Xue, J. Duan, D. Dionysiou, Y. Chen, L. Yang, Z. Guo, Purifcation of dye-stuff contained wastewater by a hybrid adsorption-periphyton reactor (hapr): performance and mechanisms, Scien. Reports, 7 (2017) 9635.
[7] E. Malkoc, Application of adsorbents for water pollution control, Bentham, Turkey, 2012.
[8] L. Lou, B. Wu, L. Wang, X. Xu, J. Hou, B. Xun, B. Hu, Y. Chen, Sorption and ecotoxicity of pentachlorophenol polluted sediment amended with rice straw derived biochar, Bioresour. Technol., 102 (2011) 4036–4041.
[9] X. Chen, G. Chen, L. Chen, Y. Chen, J. Lehmann, M. McBride, A. Hay, Adsorption of copper and zinc by biochars produced from pyrolysis of hardwood and corn straw in aqueous solution, Bioresour. Technol., 102 (2011) 8877–8884.
[10] X. Cao, G. Lena, W. Harris, Dairy-manure derived biochar effectively sorbs lead and atrazine, Environ. Sci. Technol., 43 (2009) 3285–3291.
[11] S. Rio, C. Faur–Brasquet, L. Le Coq, P. Le Cloirec, Structure characterization and adsorption properties of pyrolyzed sewage sludge, Environ. Sci. Technol., 39 (2005) 4249–4257.
[12] F. Shisuo, T. Jie, W. Yi, L. Zhang, H. Tang, J. Wang, S. Xuede, Biochar prepared from co-pyrolysis of municipal sewage sludge and tea waste for the adsorption of methylene blue from aqueous solutions: Kinetics, isotherm, thermodynamic and mechanism, J. Molec. Liq., 220 (2016) 432–441.
[13] Y. Askar, P. Jago, M. Mourad, D. Huisingh, The Cement Industry in Egypt: Challenges and Innovative Cleaner Production Solutions‖ Knowledge 177 Collaboration and Learning for Sustainable Innovation ERSCP–EMSU Conference, Delft, The Netherlands, October (2010) 25–29.
[14] H. El-Awady, Disperse and vat dyestuffs removal using cement kiln dust Egypt, J. Appl. Sci., 11 (1996) 191–201.
[15] E. Mahmoued, Cement kiln dust and coal filters treatment of textile industrial effluents, Desalination, 255 (2010) 175–178.
[16] APHA, Standard Methods for Examination of Water and Wastewater. 19th ed., American Public Health Association. American Water Environment Federation. Washington. DC. 1995.
[17] S. Mathur, H. Owen, S. Dinel, M. Schnitzer, Determination of compost biomaturity I. Literature review, Biol. Agric. Hortic., 10 (1993) 65–85.
[18] R. Gowrisankar, R. Palaniappan, S. Ponpandi, Microbiota of textile mill effluent treatment and effect of treated effluent on plant growth, J. Ind. Polln. Contl., 13 (1997) 61–65.
[19] Metcalf & Eddy, Wastewater Engineering: Treatment, Disposal, Reuse, McGraw-Hill, Inc, New York, 1991.
[20] R. Linsley, B. Joseph, D. Franzini, G. Freyberg, Water Resources Engineering, Fourth Edition McGraw–Hill, Inc., New York, 1992.
[21] W. Eckenfelder, Industrial Pollution Control, McGraw-Hill, New York, 1989.
[22] W. Stumm, J. Morgan, Aquatic Chemistry, Wiley, New York, 1996.
[23] D.S. El Monayeri, N.N. Atta, S. El Mokadem, A.M. Aboul-fotoh, Effect of organic loading rate and temperature on the performance of horizontal biofilters, Eleventh International Water Technology Conference, IWTC11 Sharm El-Sheikh, Egypt (2007) 671–682.
[24] L. Brewer, D. Sullivan, Maturity and stability evaluation of composted yard trimmings, Comp. Sci. Util., 11 (2003) 96–112.
[25] US. Environmental Protection Agency (EPA), Water quality criteria, 1993.
[26] M. Inyang, B. Gao, Y. Yao, Removal of heavy metals from aqueous solution by biochars derived from anaerobically digested biomass, Biores. Technol., 110 (2012) 50–56.
[27] X. Dong, L.Q. Ma, Y. Zhu, Y. Li, B. Gu, Mechanistic investigation of mercury sorption by brazilian pepper biochars of different pyrolytic temperatures based on X-ray photo electron spectroscopy and flow calorimetry, Environ. Sci. Technol., 47 (2013) 12156–12164.
[28] H. Lu, Y. Zhang, X. Huang, S. Wang, R. Qiu, Relative distribution of Pb^{2+} sorption mechanisms by sludge-derived biochar, Water Res., 46 (2012) 854–862.
[29] X.J. Tong, J.Y. Li, J.H. Yuan, R.K. Xu, Adsorption of Cu(II) by biochars generated from three crop straws, Chem. Eng. J., 172 (2011) 828–834.
[30] E. Mahmoud, Chemical reclamation of Alexandria municipal wastewater for unrestricted irrigation reuse. Ms. Thesis. Faculty of Agriculture, Alexandria University. 1997.
[31] Y. Yao, B. Gao, M. Inyang, Removal of phosphate from aqueous solution by biochar derived from anaerobically digested sugar beet tailings, J. Hazard. Mater., 190 (2011) 501–507.
[32] EPA, Carbon adsorption isotherms for toxic organic, EPA, 1980 600/8-80-023.
[33] M. Maurer, M. Boller, Modelling of phosphorus precipitation in wastewater treatment plants with enhanced biological phosphorus removal, Water Sci. Technol., 39 (1999) 147–163.
[34] US. Environmental Protection Agency (EPA), Water Quality Criteria, 1993.
[35] Law 48/1982. Standards for the Protection of the River Nile and Water Streams from Pollution. Egypt: Ministry of Water Resources and Irrigation; 1982.