Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2013.810384

52 (2014) 4698–4704
July

Taylor & Francis
Taylor & Francis Group

Application of cement kiln dust for chemically enhanced primary treatment of municipal wastewater

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Received 29 June 2012; Accepted 12 May 2013

ABSTRACT

Chemically enhanced primary treatment (CEPT) involves the use of chemical coagulants to enhance the coagulation or flocculation of wastewater particles. Chemicals of aluminum sulfate (alum), cement kiln dust (CKD), and cationic polymer were studied with jar test to select the most suitable coagulant for effective treatment of municipal wastewater. The results reveal that CKD at dose $50\,\mathrm{mg\,l^{-1}}$ could remove about 58.7% of chemical oxygen demand (COD) and 60% of biochemical oxygen demand (BOD). The addition of $50\,\mathrm{mg\,l^{-1}}$ of CKD and of $0.2\,\mathrm{mg\,l^{-1}}$ of polyacrylamide flocculant (PAM) could provide a reduction of BOD, COD, phosphorous, and fecal coliform (FC) with percentages higher than 79, 85, 95, and 99.9%, respectively. Heavy metals, salinity, sodicity, phosphorous concentrations, and pH of the treated wastewater by (CKD + PAM) are within the acceptable range for irrigation. FC numbers was 1400 Most Probable Number (MPN)/100 ml for the CEPT effluent, and it is not meeting the WHO guideline for FC of 1000 MPN/100 ml. The experimental results confirmed that CEPT can be used as a simple low-cost technology, and as an effective treatment of municipal wastewater, to improve the efficiency of recycled CKD.

Keywords: Municipal wastewater; Irrigation; Cement kiln dust; Chemically enhanced primary treatment (CEPT)

1. Introduction

Wastewater treatment and reuse needs to be considered within an integrated water resources management and environmental protection strategy. The purpose of wastewater treatment is to remove organic matter and other pollutants from solution. Water quality criteria for irrigation generally take into account characteristics such as crop tolerance to salinity, sodium concentration, and phytotoxic trace elements. Egypt's population continues growing, but available water resources do not. It is imperative, therefore, to reuse both drainage and treated wastewater. At present, effluents from wastewater treatment plants (WWTPs), which exceed 3 Billion $\mathrm{m^3}$/year, are mainly discharged into agricultural drains [1]. Wastewater is often a reliable year-round source of water, and it contains the nutrients necessary for plant growth. The value of wastewater has long been recognized by farmers worldwide. The use of wastewater in agriculture is a form of nutrient and water recycling, and this often reduces downstream environmental impacts on soil and water resources. The wastewater treatment methods must be improved in order to produce effluents having a microbiological load within the WHO allowed limits [2]. In view of economic reality, we need to develop a simple and cost-effective system for its treatment. Chemically enhanced primary treatment (CEPT) is tenable as an appropriate, executive, and effective method. This technology does not only bring proper and comparable results in terms of reducing the chemical oxygen demand (COD), turbidity, and TSS in comparison with current systems, but also implies a very cost-effective and productive method to upgrade the capacity of conventional plants [3].

In recent years, CEPT that utilizes a chemical coagulant to assist the removal of suspended and dissolved contaminants has drawn wide attention for wastewaters that are not amenable to conventional biological treatment (energy processes) [4,5]. The CEPT for municipal wastewater treatment is restricted to physico-chemical processes; involving coagulation/ flocculation and adsorption/ precipitation mechanisms. It is based on colloid principles and wastewater chemistry to transform suspended and some soluble contaminants to a solid phase. Organic pollution is of primary concern; usually expressed as the biochemical oxygen demand (BOD) which approximates the quantity of oxygen required to biologically stabilize the organic matter present. The BOD is a key water quality variable highly correlated with other water quality variables. CEPT for municipal wastewater treatment is cost-effective and, particularly, suitable for rapidly growing mega-cities and developing countries. The main problems of CEPT are the cost of chemicals and the production of excessive sludge volumes. Conventional chemical treatment processes produce about 1.5–2.0 much more sludge than that produced by conventional primary treatment [6,7]. The cost of waste sludge disposal is a major factor in the operational cost of WWTPs, 30–50% of the annual operating cost is related to sludge dewatering alone [6]. Coagulation sludge (after coagulation in water treatment and CEPT process) contains large amount of coagulant, thus the sludge, as a resource recovered from CEPT, could be an effective way to reduce the disposal sludge volume and to save the dosage cost [8].

Cement kiln dust (CKD) is a fine powdery material that is collected from kiln exhaust gasses during the manufacture of Portland cement. The generation of CKD is approximately 30 million tons worldwide per year [9]. More than 2.5 million tons per year are generated in Egypt, and they are considered hazardous materials with high cost disposal [10]. Mahmoud [11] observed that CKD filter could greatly reduce organic matter and other pollutants in raw textile wastewater.

The safety of reclaimed water irrigation is doubted by the public [12]. Concerns for reclaimed water irrigation in agricultural and landscape mainly focus on: (1) soil salinization and plant hazards; (2) soil accumulation of toxic metals and subsequent plant transfer; (3) ground water contamination of salts and emerging contaminants; and (4) public health issues from pathogens. The greatest health concern in using reclaimed wastewater for irrigation is directed to pathogens. Through proper treatment and disinfection of wastewater, most pathogens will be removed or inactivated. However, concentrations of some pathogens like viruses and Giardia in reclaimed water may be still higher than their infective dose. An individual can acquire disease from reclaimed water use by: direct ingestion of the reclaimed water or aerosols created during spray irrigation, ingestion of pathogens on contaminated vegetation or other surfaces, and ingestion of ground water below sites irrigated with reclaimed water that has been contaminated by pathogens. So far, evidence supporting the spread of disease through irrigation with reclaimed water is scarce. The potential for disease transmission through reclaimed water reuse, however, has not been completely eliminated. Except for the quality of 16 reclaimed water, many factors, including plant type, irrigation method, cultural and harvesting practices, and environmental conditions (temperature and humidity), can affect the transmission of disease [13]. The potential for human exposure can be minimized by: (1) improving irrigation methods such as drip irrigation and (2) building proper setback distances, or buffer zones, between reuse sites and other facilities such as potable water supply wells, property lines, residential areas, and roadways [14].

The objective of this study is to investigate the effect combining CKD and alum with a cationic polymer on removing organic substances (BOD and COD) and other pollutants from three municipal WWTPs and its treated wastewater with regard to water criteria for irrigation.

2. Materials and methods

2.1. Wastewater sampling and raw materials

The raw sewage samples were collected from the effluent of Alexandria East, Kafr El-Dawar and Damanhour WWTPs, after the initial screening process. Laboratory investigation was carried out immediately (within 24 h) after the collection to minimize any changes in the sewage characteristics. CKD is obtained from El-Amerya of cement plants. CKD is an alkaline waste material ($\mathrm{pH} \approx 12.3$) and its main components are calcium carbonate (47.6%);

oxides of aluminum (4.2%); iron (2.8%); magnesium (2.3%); free lime (4.8%); and some alkali salts such as sodium and potassium. Its specific gravity is 2.92 and its specific surface area is 4,440 cm^2/g. Mahmoud [15] examined CKD of varying dose for treated municapial wastewater and found that the maximum COD and BOD removal occurred at dose a of 50 $\mathrm{mg\,l}^{-1}$. Stock Alum ($Al_2(SO_4)_3$ n H_2O) solution (1,000 ppm) was prepared. The cationic polymer used was a commercially available high molecular weight polyacrylamide flocculant (PAM). The detailed molecular structure of the product was not shown, but the general properties are molecular weights (7×10^7), pH (6–7), bulk density (0.5 $\mathrm{g\,cm}^{-3}$), and physical form (white granular powder). The stock polymer solution was prepared by adding 0.5 g of the cationic polymer (Zetag 63, supplied by Applied Colloids) to 3 ml of methanol in order to thoroughly dissolve the product. Then, 97 ml of distilled water was added and the mixture was shaken well for 10 min and further stirred with a magnetic stirrer overnight. This procedure resulted in a 500 ppm stock polymer solution.

2.2. Jar test and analysis

A raw domestic wastewater sample (1,000 mL) was combined to CKD and alum as coagulants. This combination was rapidly mixed for 1 min at 100 rpm (rpm), after which a flocculants (PAM) was added. This was followed by a slow mixing for 10 min at 20 rpm. The wastewater was then allowed to settle for 40 min and the supernatant was taken to be measured for the pH, EC, BOD, COD, phosphorus, and heavy metals. The pH was determined by pH Controller Model 5,997; and EC was measured by CDM 83 conductivity meter. BOD_5 and COD concentrations were measured according to standard methods [16]. Fecal coliform (FC) was estimated according to standard methods [16]. The FC procedure using A-1 medium (DIFCO) was employed (Standard 9,221 E). After inoculating the A-1 broth tubes, they were incubated for 3 h at 35 ± 0.5 °C. Tubes were then transferred to another incubator at 44 ± 0.2 °C for an additional 21 ± 2 h. Gas production in any A-1 broth culture within 24 h or less was considered a positive reaction indicating the presence of FCs. The Most Probable Number (MPN) index was calculated from the number of positive A-1 broth tubes as described in (Standard 9,221 C). Phosphorus was estimated by the vanadomolybdophosphoric acid colorimetric method [16]. Water samples were filtered when necessary and heavy metals measured by flame atomic absorption.

3. Results and discussion

3.1. Characteristics of used municipal wastewater

Table 1 presents the characteristics of three municipal WWTPs; the total dissolved soils (TDS) ranged from 665 to 1,702 $\mathrm{mg\,l}^{-1}$with average of 1,693, whereas the tap water is usually ranged within 450 $\mathrm{mg\,l}^{-1}$. The increase in the mineral content of the municipal wastewater results from domestic water use. pH ranged from 7.14 to 7.56.

Concentrations of BOD and COD ranged from 180 and 329 to 296 and 388 $\mathrm{mg\,l}^{-1}$, respectively. This would classify the wastewater as medium strength [17]. The calculated BOD to COD ratio was 0.5:0.89 as range. Data show that contaminant loads in Damanhour are higher than Alexandria East and Kafr El-Dawar WWTPs.

3.2. Effect of alum dose on removal efficiency

Fig. 1 illustrates the effect of alum dose on both COD and BOD removal efficiency in the samples taken from Kafr El-Dawer wastewater plant. Increasing alum dose from 30 to 100 $\mathrm{mg\,l}^{-1}$ provided high COD and BOD removal. A maximum removal of 50% and 60% for COD and BOD with respect to raw wastewater occurred at an alum dose of 50 $\mathrm{mg\,l}^{-1}$. At alum doses above 50 $\mathrm{mg\,l}^{-1}$, there was no further appreciable reduction in COD and BOD. Thus, 50 $\mathrm{mg\,l}^{-1}$ of alum was chosen for the next phase of experiments. Coagulation with alum involves three steps [18]: (i) destabilization begins after the operational solubility limit of aluminum hydroxide has been exceeded; (ii) aluminum hydroxide species are then deposited onto the colloidal surfaces; and (iii) under typical conditions, the aluminum hydroxide is positively charged, while the original colloidal particles are negatively charged.

3.3. Effect of cationic polymer dose on removal efficiency

Fig. 2 shows the effect of varying polymer dose on COD and BOD removal with a fixed dose of 50 $\mathrm{mg\,l}^{-1}$ of CKD in the samples taken from the Damanhour WWTP. It can be seen that a maximum percentage removal of 85% for COD and 79% for BOD occurred at a cationic polymer dose of 0.2 $\mathrm{mg\,l}^{-1}$. Further increase in the polymer dose did not improve or even decrease the removal efficiency. The latter might be due to the so-called overdosing phenomenon. Similar effects have been previously noted in water and industrial wastewater treatment studies [19]. Above the optimum dosage (0.2 $\mathrm{mg\,l}^{-1}$), it was marked that

Table 1
Raw wastewater characteristics of 13 mornings grab samples obtained between January 2010 and March 2011 for three wastewater treatment plants

Wastewater treatment plants	Date	pH	TDS	PO_4^{-3}	COD	BOD	BOD/COD
			$mg\,l^{-1}$				
Alexandria East	13/1/2010	7.14	691.2	22.2	338	244	0.72
Alexandria East	22/1/2010	7.46	768.0	14.2	388	216	0.55
Alexandria East	18/12/2010	7.23	665.6	16.5	365	202	0.55
Alexandria East	3/2/2011	7.36	678.4	28.3	376	285	0.76
Damanhour	3/2/2010	7.55	1446.4	35.8	329	270	0.82
Damanhour	2/5/2010	7.52	1702.4	40.3	329	296	0.89
Damanhour	16/2/2010	7.43	1420.8	22.2	357	180	0.50
Damanhour	2/3/2010	7.56	1286.4	21.2	329	270	0.82
Kafr El-Dawer	20/2/2010	7.37	825.6	16.5	357	211	0.59
Kafr El-Dawer	26/11/2010	7.32	832.6	11.2	345	220	0.64
Kafr El-Dawer	5/3/2010	7.42	665.6	13.7	357	173	0.48
Kafr El-Dawer	26/11/2010	7.34	691.2	11.7	345	220	0.64
Kafr El-Dawer	15/3/2011	7.35	684.6	18.6	386	218	0.56

Note: BOD_5: Biological oxygen demand at 5 days. COD: Chemical oxygen demand.

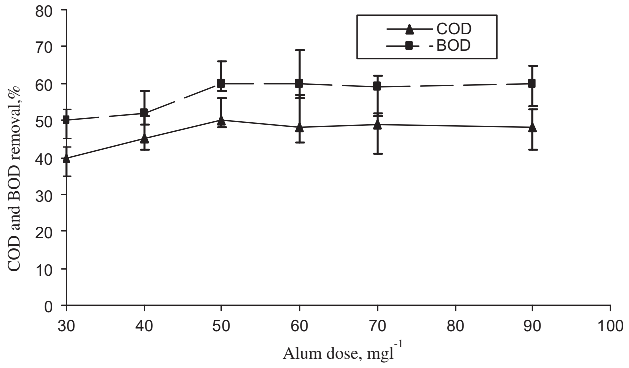

Fig. 1. Effect of an alum dose on COD and BOD_5 removal (bars indicate the standard deviation). BOD_5: Biological oxygen demand at five days COD: Chemical oxygen demand.

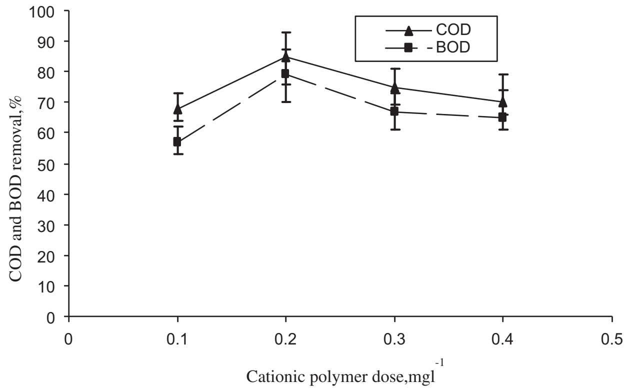

Fig. 2. Effect of a cationic polymer dose on COD and BOD_5 removal at a fixed CKD dose. (bars indicate the standard deviation).

the parts of polymer separated in solution and a reduction in floc size which led to increase in the COD and BOD. Polymer dose higher than 0.2 $mg\,l^{-1}$ reduced BOD and COD removal efficiency. Thus, 0.2 mg $l^{-1}$of alum was chosen for the next phase of experiments.

3.4. Comparison of removal efficiencies of two CEPT options

A comparison of the percentage of the removals of various parameters has been presented for the two CEPT options in (Table 2). The percentage of the removals of COD, BOD, and PO_4^{-3} from raw wastewater for CKD + PAM is better than alum + PAM options. The use of CKD and alum with cationic polymer showed improvement in removal of COD and BOD. Moreover, the addition of polymer with CKD and alum resulted in the formation of big flocs. The

Table 2
Comparison of removal efficiencies of two CEPT options

Removals,%		CKD + PAM Range ($n = 9$)	Alum + PAM Range ($n = 9$)
COD	Min.	73.9	75.4
	Max.	86.7	84.1
	Av.	82.4	78.8
BOD	Min.	72.7	75.9
	Max.	85.3	84.2
	Av.	79.7	76.0
PO_4^{-3}	Min.	91.7	75.8
	Max.	97.7	83.7
	Av.	95.0	78.4

combination of alum with suitable cationic polymer resulted in effluent COD removal at an average of 78.8%; BOD removal of 76.0%; and PO_4^{-3} removal of 78.4%, while COD, BOD, and PO_4^{-3} removals were 82.4, 79.7, and 95% for treated wastewater by CKD + PAM, respectively. Thus, CKD + PAM were chosen for comparison with water criteria for irrigation. Such removal can be accounted for by adsorption or adsorption/ precipitation mechanism. The BOD and COD adsorption mechanism is complicated because it is a combination of physical, chemical, and electrostatic interactions between the CKD and the organic compounds although the attraction is primarily physical [20]. In fact, it has been stated that chemical precipitation using alum and CKD coagulants is effective for phosphorus removal [20]. Alum reduced dissolved inorganic phosphate levels through the precipitation of insoluble aluminum phosphate. Polyphosphates and other organic phosphorus compounds may also be removed by being entrapped, or adsorbed in the floc particles [21]. Reduction of phosphorus by CKD may be attributed to the adsorption of phosphorus on calcium carbonate existing in CKD and may also be reduced by precipitation with high pH.

3.5. Treated wastewater quality to meet water criteria for irrigation

The characteristics of raw wastewater samples before and after treatment, using CKD + PAM compared to water criteria for irrigation, is shown in (Table 3). Concentrations of BOD and TDS in the treated wastewater by CKD + PAM ranged from 44 and 696 to 73 and $1{,}702\,\mathrm{mg\,l^{-1}}$, respectively. Whereas, the drainage waters now reused in the Delta exceed 4 $\mathrm{B\,m^3}$/year, ranging 48–221 mg/l in BOD and 539–2,394 mg/l in TDS [1]. In general, the treated wastewater of CEPT had lower levels of salinity and BOD than reused drainage waters in the Nile Delta. With regard to salinity and sodium adsorption ratio (SAR), treated water can be considered as entirely safe for irrigation purpose because of its medium salinity and low sodicity (Class C2 S1) [2], and it can be considered as an excellent class type for irrigation [22]. CEPT decreases SAR of the raw wastewater because the CKD tends to release calcium and magnesium during treatment. SAR of treated water fell within the acceptable range for irrigation [2,19]. According to [2,22], the normal pH for irrigation water ranges from 6.5 to 8.4. Generally, the present value of pH remains within the safe range for irrigation.

The average amount of phosphorus in the raw wastewater was $24.35\,\mathrm{mg\,l^{-1}}$, and only $1.2\,\mathrm{mg\,l^{-1}}$ of PO_4^{-3} remained in the CEPT effluent (Table 3), corresponding to an average PO_4^{-3} removal efficiency of 95%. Thus, most of the PO_4^{-3} was eliminated from the wastewater with the sludge. Heavy metal concentrations of the treated water of CEPT are within the acceptable range for irrigation [22]. In fact, heavy metals were reduced in the treated wastewater by CKD; presumably this is due to adsorption/ precipitation reactions. Reduction of heavy metals by CKD may be attributed to adsorption of heavy metals on calcium carbonate existing in CKD. In the formation of surface metal-complexes, these complexes may be formed due to the interaction of metal with surface sites of oxides such as Fe–OH, Al–OH, and Si–OH that are found in CKD and may also be reduced by precipitation with high pH [23,11]. Mackie et al. [24] demonstrated that CKD leachate was effective in removing copper, nickel, and zinc ions from a synthetic wastewater by hydroxide precipitation. El-Awady and Sami [25] found that CKD was efficient in the removal of heavy metals from synthetic aqueous solutions. FC can be used as reasonably reliable indicators of bacterial pathogens. Raw wastewaters contain about 10^7–10^9 FCs per 100 ml, and some 10^3 helminth eggs per liter where helminth infections are prevalent [26]. FC numbers was 1,400 MPN/ 100 ml for the CEPT effluent (Table 3). Removal of bacteria may involve adsorption on the solid particles during the flocculation/sedimentation process. The CEPT is not meeting the WHO guideline for FC of 1,000 MPN/100 ml; several environmental factors are expected to affect FC survival after discharge in the receiving canals. Higher temperature usually increases bacterial mortality, but it can also promote FC regrowth in aquatic environments [27]. Fecal mortality rates increase with solar intensity and pH [28]. The remaining 1,400 MNP/100 ml of FC is still too large for safe irrigation reuse. Risk associated with reuse is directly related to ingestion and contact with the human body. Precautionary measures could be

Table 3
Characteristics of raw wastewater samples before and after treatment, using CKD + PAM compared to water criteria for irrigation

Parameters	Units	Crude sewage, $n = 9$	CKD + PAM; range ($n = 9$)	Removal%	Water criteria of irrigation[a]
pH		7.14–7.6	7.55–8.2		6.5–8.4
TDS	mg l^{-1}	665–1,728	696–1,702		2000
SAR		10.2–9.5	5.4–6.0		6–12
COD	mg l^{-1}	329–439	66–76	73.9–86.7	60[b]
BOD	mg l^{-1}	270–296	44−73	72.7–85.3	40[b]
PO_4^{-3}	mg l^{-1}	24.5–49.4	0.98−1.2	91.7–97.9	
Fe	mg l^{-1}		0.05		5.00
Zn	mg l^{-1}		0.02		2.00
Mn	mg l^{-1}		0.07		0.20
Cu	mg l^{-1}		0.04		0.20
Cd	mg l^{-1}		0.01		0.01
Pb	mg l^{-1}		0.89		5.00
Ni	mg l^{-1}		0.18		0.20
Fecal coliform	MPN /100 ml		1,400		10^3–10^4

[a][2,22]222 WHO (2006) US. EPA (1993). [b][30] Egypt (48/1982).

recommended for reducing the contact between reclaimed water and the irrigator, such as irrigation method (Inc. drip, trickle and bubbler irrigation) and stop irrigation before harvest (1–2 weeks). Need for effective but affordable disinfecting treatment is of paramount importance [14]. However, CEPT is meeting the WHO (2006) guideline for FC of 10,000 MPN/100 ml.

The CEPT can be adopted in the reclamation of wastewater, as it can achieve 82.4% of COD, 79.7% of BOD, and 95% of PO_4^{-3} removal at average (Table 2), which is similar to a secondary wastewater treatment plant (SWTP); but with no cost. The SWTP requires a large tank with activated sludge maintained in suspension by an aeration system with DO control; operation; maintenance; and land costs. For the secondary treatment, estimated total unit cost (investment plus running cost) is around \$2.0 m^{-3} [26]. In this study, the cost of chemicals to treat one cubic meter of wastewater was only \$ 0.05 m^{-3}.

4. Conclusion

This study showed that the combination of CKD with a cationic polymer had a good effect on the removal of organic matter and other pollutants from municipal wastewater. Heavy metal, salinity, sodicity, phosphorous concentrations, and pH of the treated wastewater of CEPT (CKD + PAM) are within the acceptable range for irrigation. Cost of the chemicals to treat one cubic meter of wastewater was below \$ 0.05 m^{-3}. Thus, CEPT (CKD + PAM) can be used as a simple low-cost technology and, low-cost for municipal wastewater treatment to improve the efficiency of CKD disposal.

Acknowledgment

I wish to thank the Alexandria East, Kafr El-Dawar and Damanhour wastewater treatment plants, Egypt, for providing the wastewater samples, and thank Tanta University, Faculty of Agriculture for support in realizing this work.

References

[1] DRI National Water Research Center, Drainage water status in the Nile Delta, Ministry of Water Resources and Irrigation, Egypt, 2000.

[2] World Health Organization (WHO), Guidelines for the safe use of wastewater, excreta and greywater. Volume 2, Wastewater use in agriculture, Geneva, 2006.

[3] J.C. Huang, L. Li, Enhanced primary wastewater treatment by sludge recycling, J. Environ. Sci. Health. Part A Toxic/Hazard. Subst. Environ. Eng. 35(1) (2000) 123–145.

[4] D. Harleman, S. Murcott, The role of physical–chemical wastewater treatment in the mega-cities of the developing world, Environ. Sci. Technol. 40 (1999) 75–80.

[5] C.S. Poon, C.W. Chu, The use of ferric chloride and anionic polymer in the chemically assisted primary sedimentation process, Chemosphere 39 (1999) 1573–1582.

[6] J.C. Huang, L. Li, An innovative approach to maximize primary treatment performance, Environ. Sci. Technol. 42 (2000) 209–222.

[7] L. Semerjian, G.M. Ayoub, High-pH-magnesium coagulation-flocculation in wastewater treatment, Adv. Environ. Res. 7 (2003) 389–403.

[8] G.R. Xu, Z.C. Yan, Y.C. Wang, N. Wang, Recycle of alum recovered from water treatment sludge in chemically enhanced primary treatment, J. Hazard. Mater. 161 (2009) 663–669.

[9] G.A. Miller, S. Azad, Influence of soil type on stabilization with cement kiln dust, Constr. Build. Mater. 14(2) (2000) 89–97.

[10] M.S. El-Haggar, Utilization of cement by- pass dust for sludge treatment. EEAA Conference on Cement by-pass dust, Maadi Sofetel Hotel (2002).

[11] E.K. Mahmoud, Cement kiln dust and coal filters treatment of textile industrial effluents, Desalination 255 (2010) 175–178.

[12] F. Pedrero, I. Kalavrouziotis, J.J. Alarcòn, P. Koukoulakis, T. Asano, Use of treated municipal wastewater in irrigated agriculture: Review of some practices in Spain and Greece, AGR Water Manage. 97(9) (2010) 1233–1241.

[13] C. Levantesi, R. La Mantia, C. Masciopinto, U. Bockelmann, M.N. Ayuso-Gabella, M. Salgot, V. Tandoi, E. Van Houtte, T. Wintgens, E. Grohmann, Quantification of pathogenic microorganisms and microbial indicators in three wastewater reclamation and managed aquifer recharge facilities in Europe, Sci. Total Environ. 408 (2010) 4923–4930.

[14] W. Chen, S. Lu, W. Jiao, M. Wang and A.C. Chang, reclaimed water: A safe irrigation water source?, Environ. Develop. Available from http://dx.doi.org/10.1016/j.envdev.2013.04.003.

[15] E.K. Mahmoud, Chemical reclamation of Alexandria municipal wastewater for unrestricted irrigation reuse, Ms thesis, Faculty of Agriculture, Alexandria University, 1997.

[16] APHA, Standard Methods for Examination of Water and Wastewater, nineteenth ed., American Public Health Association. American Water Environment Federation, Washington, DC, 1995.

[17] Metcalf & Eddy, Wastewater Engineering: Treatment, Disposal, Reuse, McGraw-Hill, New York, 1991.

[18] S.K. Dentel, Coagulant control in water treatment, Crit. Rev. Environ. Control 21 (1991) 41–135.

[19] E.K. Mahmoud, Chemically enhanced primary treatment of textile industrial effluents, Pol. J. Environ. Stud. 18 (2009) 651–655.

[20] W. Stumm, J. Morgan, Aquatic Chemistry, Wiley, New York, 1996.

[21] J.C. Hunng, Chemically enhanced primary treatment for sewage in Hong Kong, in: Proceedings of Chartered Institution of Water, Environmental Management, London, 1995, pp. 49–53.

[22] US. Environmental Protection Agency (EPA), Water quality criteria, 1993.

[23] K. Farley, A. Dzombak, F. Morel, A surface precipitation model for the sorption of cations on metal oxides, J. Colloid Interface Sci. 106 (1985) 226–242.

[24] A. Mackie, S. Boilard, M.E. Walsh, C.B. Lake, Physicochemical characterization of cement kiln dust for potential reuse in acidic wastewater treatment, J. Hazard. Mater. 173 (2010) 283–291.

[25] M.H. El-Awady, T.M. Sami, Removal of heavy metals by cement kiln dust, Bull. Environ. Contam. Toxicol. 59 (1997) 603–610.

[26] WHO, Health Guidelines for Use of Wastewater in Agriculture and Aquaculture. World Health Organization, Technical Report Series 778. WHO, Geneva, Switzerland, 1989.

[27] J.M. Howell, M.S. Coyne, P.L. Cornelius, Effect of sediment particle size and temperature on fecal bacteria mortality rates and the fecal coliform/fecal streptococci ratio, J. Environ. Qual. 25 (1996) 1216–1220.

[28] A.W. Mayo, Modeling coliform mortality in waste stabilization ponds, J. Environ. Eng. ASCE 121(2) (1995) 140–152.

[29] R. Helmer, I. Hesphanol, Water Pollution Control, 1st ed., WHO/UNEP, London, 1997.

[30] E.C.S. (Egyptian chemical standards), Protection of Nile River and water stream from pollution, Ministry of Irrigation, Cairo, Egypt, law (48/1982).