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Low-Cost Technology for Wastewater Treatment for Irrigation Reuse

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Abstract: Reuse of wastewater in Egypt for irrigation could save scarce water supplies. The objective of this study is to investigate the reuse of wastewater for irrigation by chemically enhanced primary treatment (CEPT), as low-cost technology of wastewater treatment. Aluminum sulphate (alum), cement kiln dust (CKD) and cationic polymer (PAM) were used with jar test to select the most suitable coagulant for effective treatment of municipal wastewater. The results revealed that alum at a dose of 50 mg L^{-1} could remove about 50% of COD and 60% of BOD. At alum doses above 50 mg L^{-1}, there was no further appreciable reduction in COD and BOD. The addition of 50 mg $L^{-1}$of CKD and of 0.2 mg L^{-1} PAM could reduce BOD, COD, phosphorous and fecal coliform (FC) by about 79%, 85%, 95% and more than 99.9%, respectively. Total dissolved solids (TDS) and sodium adsorption ratio (SAR) in the wastewater treated by CKD + PAM ranged from 696 mg L^{-1} and 5.4 to 1702 mg L^{-1} and 6.0, respectively. Heavy metals, SAR, TDS and pH of the wastewater treated by (CKD + PAM) were within the acceptable range for irrigation. Fecal coliform numbers was 1400 MPN /100 mL for the CEPT effluent, *i.e.* it exceeded the WHO guideline for FC of 1000 MPN/100 mL. Thus, CEPT (CKD+ PAM) can be used as a simple low-cost technology for municipal wastewater treatment and for improving the efficiency of cement kiln dust disposal.

Key words: Irrigation · Municipal Wastewater · Fecal Coliform · Cement Kiln Dust · Low-Cost Technology

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 reduce contents of the organic and inorganic pollutants in the treated wastewater. Water quality criteria for irrigation generally take into account characteristics such as crop tolerance to salinity, sodium concentration and phytotoxic trace elements. Egypt population continues growing, but available water resources are still almost constant, therefore it is imperative to reuse treated wastewater (drainage, sewage and industrial waste waters for irrigation to overcome the gap between the amount of available water and the required one). At present effluents from wastewater treatment plants (WWTPs), which exceed 3 Billion m^3/year is mainly discharged into agricultural drains [1]. Wastewater is often a reliable year- round source of water and it contains some nutrients necessary for plant growth. 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 feasibility, we need to develop a simple and cost-effective system for 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 COD, turbidity and TSS in comparison with traditional techniques, but also implies a very low 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 chemically enhanced primary treatment 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

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suspended and some soluble contaminants to a solid phase. 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 wastewater treatment plants, 30-50% of the annual operating cost is related to sludge dewatering alone [6]. Coagulation of sludge 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].

CKD is a fine powdery material that is collected from kiln exhaust gases during the manufacture of Portland Cement (PC). The generation of CKD is approximately 30 million tons world wide 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.

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 by salts and emerging contaminants; (4) public health issues from pathogens. The greatest health concern in using reclaimed wastewater for irrigation is directed to pathogens [12]. 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, ingestion of ground water below sites irrigated with reclaimed water that has been contaminated by pathogens. However, 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 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, residential areas and roadways [14].

The objective of this study is to investigate the effect of CKD, alum, cationic polymer and their combination, on reducing organic substances and other pollutants from municipal wastewater and assessing treated wastewater with regard to water criteria for irrigation.

MATERIAL AND METHODS

Wastewater Sampling and Raw Materials: The raw sewage water samples were collected from the effluents of Alexandria East, Kafr El-Dawar and Damanhour wastewater treatment plants, after the initial screening process in period from January 2010 till March 2011. Laboratory investigation was carried out immediately (within 24 hours) after the collection to minimize any changes in the sewage characteristics. Cement kiln dust (CKD) sample collected from El-Amerya of Cement Plant Company was analyzed by x-ray as shown in Table 1. Previous research has demonstrated that the maximum COD and BOD removal occurred at a dose of 50 mg CKD L^{-1} [15]. Stock Alum ($Al_2(SO_4)_3$ n H_2O) solution (1000 ppm) was prepared and its doses used in the study were 30, 40, 50, 60, 70 and 90 mg L^{-1}. The cationic polymer (Zetag 63, supplied by Applied Colloids) used was a commercially available high molecular weight polyacrylamide flocculant (PAM). The general properties of the product are molecular weights ($7*10^7$), pH (6-7), bulk density (0.5 g cm^{-3}) and physical form (white granular powder). The stock polymer solution was prepared by adding 0.5 g of the cationic polymer to 3 mL methanol in order to thoroughly dissolve the product.97 mL distilled water was then added and the mixture was shaken well for 10 minutes and further stirred with a magnetic stirrer overnight. This procedure resulted in a 500 mg L^{-1} stock polymer solution and its doses used in the study were 0.1, 0.2, 0.3, 0.4 and 0.5 mg L^{-1}.

Table 1: Chemical analysis of cement kiln dust (CKD).

Oxides	Composition (wt %)
SiO_2	13.6
Al_2O_3	4.2
Fe_2O_3	2.8
CaO	47.6
MgO	2.3
Na_2O	2.2
K_2O	2.5
Free lime	4.8
pH	12.3
Specific surface area (cm^2g^{-1})	4440

Jar Test and Analysis: A raw domestic wastewater sample (1000 mL) was combined to CKD and alum as coagulants. This combination was rapidly mixed for 1 min at 100 revolutions per minute (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 minutes and the supernatant was taken to be measured for the pH, EC, biological oxygen demand (BOD), chemical oxygen demand (COD), phosphorus and heavy metals. The pH was determined by pH Controller Model 5997; and EC was measured by CDM 83 conductivity meter. BOD$_5$ and COD as well as fecal coliform (FC) were determined according to standard methods [16]. The fecal coliform procedure using A-1 medium (DIFCO) was employed (Standard 9221 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 fecal coliforms. The Most Probable Number (MPN) index was calculated from the number of positive A-1 broth tubes as described in (Standard 9221 C). Phosphorus was estimated by the vanadomolyb dophosphoric acid colorimetric method [16]. Water samples were filtered when necessary and heavy metals measured by atomic absorption spectrophotometer model (Perkin Elmer AA model 2380.).

RESULTS AND DISCUSSION

Characteristics of the Used Municipal Wastewater: Table 2 shows the characteristics of three studied municipal wastewaters treatment plants, the total dissolved solids (TDS) ranged from 665 to 1702 mg L^{-1} with 1693 mg L^{-1}as an average, whereas the tap water content of the total dissolved solids is usually flocculating around 450 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 mg L^{-1} respectively, which classify the wastewater as medium strength [17]. The calculated BOD to COD ratio ranged from 0.5 to 0.89. Data shows that contaminant loads in Damanhour wastewater are higher than those of Alexandria East and Kafr El-Dawar wastewater treatment plants.

Effect of Alum Dose on Removal Efficiency: Figure 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 mg L^{-1} caused higher removal of COD and BOD. Maximum removal values of 50% and 60% for COD and BOD compared with raw wastewater occurred at an alum dose of 50 mg L^{-1}. At alum doses above 50 mg L^{-1}, there was no further appreciable reduction in COD and BOD.

Table 2: Raw wastewater characteristics of 13 mornings grab samples obtained between January 2010 and March 2011 for three wastewater treatment plants.

			TDS	PO$_4^{-3}$	COD	BOD	
Wastewater treatment plants	Date	pH	mg l^{-1}				BOD/COD
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

BOD$_5$: Biological oxygen demand at 5 days.

COD: Chemical oxygen demand.

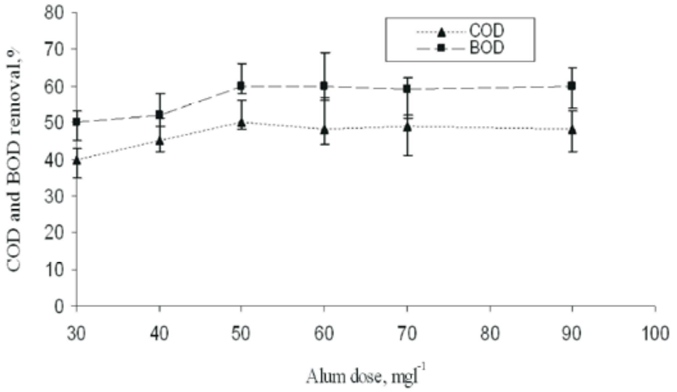

Fig. 1: Effect of alum dose on COD and BOD_5 removal (bars indicate the standard deviation).

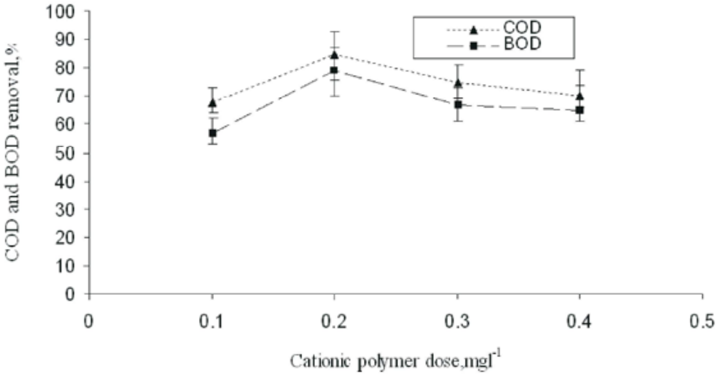

Fig. 2: Effect of the cationic polymer dose on COD and BOD_5 removal at a fixed CKD dose. (bars indicate the standard deviation).

Thus, 50 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; (iii) under typical conditions, the aluminum hydroxide is positively charged, while the original colloidal particles are negatively charged.

Effect of Cationic Polymer Dose on Removal Efficiency: Figure 2 shows the effect of varying polymer dose on COD and BOD removal with a fixed dose of 50 mg L^{-1} of CKD in the samples taken from Damanhour wastewater treatment plant. It can be seen that a maximum removal percentages of 85% for COD and 79% for BOD occurred at a cationic polymer dose of 0.2 mg L^{-1}. No further increase in the polymer dose could improve or even decrease the removal efficiency. This might be due to the so-called overdosing. Similar effects have been previously noted in water and industrial wastewater treatment studies [19]. Above the optimum dosage (0.2 mg L^{-1}), it was marked that 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.

Table 3: A Comparison between 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

A Comparison Between Removal Efficiencies of the Two Cept Options: A comparison between the percentages of the removals of reductions in various parameters due to presented for the two CEPT options are presented in Table 3. The percentage of the removals of COD, BOD and PO_4^{3-} from raw wastewater due to CKD+PAM is

Table 4: 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+PAMrange (n=9)	Removal %	Water criteriaof irrigation[a]
pH		7.14-7.6	7.55 - 8.2		6.5-8.4
TDS	mg l^{-1}	665-1728	696 - 1702		2000
SAR		10.2-9.5	5.4- 6.0		6-12
COD	mg l^{-1}	329-439	66 - 76	74 -87	60[b]
BOD	mg l^{-1}	270-296	44 -73	73 -85	40[b]
PO_4^{-3}	mg l^{-1}	24.5-49.4	0.98 -1.2	92 -98	
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		1400		10^3-10^4

a [2] WHO (2006), [22] US. EPA (1993).

b [30] Egypt (44/2000).

higher than that of alum+PAM. 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 bigger flocs. The combination of alum with the cationic polymer resulted in removal of COD from the effluent averaged of 78.8%; corresponding of BOD averaged of 76.0% and PO_4^{3-} removal averaged of 78.4%. Meanwhile, the removal parentages of COD, BOD and PO_4^{3-} averaged 82.4%, 79.7% and 95%, respectively due to treating the wastewater by CKD+PAM. CKD+PAM were chosen for comparison with water criteria for irrigation. This finding can be attributed to 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.

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 are shown in (Table 4). Concentrations of BOD and TDS in the wastewater treated by CKD + PAM ranged from 44 and 696 to 73 and 1702 mg L^{-1}, respectively. The drainage waters being reused in the Nile Delta exceeds 4 B m^3/year and its contents of BOD and TSD, range from 48-221 mg L^{-1} and 539-2394 mg L^{-1} [1]. In general, the wastewater by 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 decreased SAR of the raw wastewater because the CKD tends to release calcium and magnesium during treatment. SAR of the treated water is 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, pH values of the treated waters are within the safe range for irrigation.

The average amount of phosphorus in the raw wastewater was 24.35 mg L^{-1} and only 1.2 mg L^{-1} of PO_4^{3-} remained in the CEPT treated effluent (Table 4), 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 water treated by CEPT were within the acceptable range for irrigation [22]. In fact, heavy metals were reduced in the 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. Also surface metal-complexes might 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. Also, concentrations of heavy metals may be reduced by precipitation with high pH values [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. Fecal coliform (FC) can be used as reasonably reliable indicators of bacterial pathogens. Raw wastewaters contain about 10^7-10^9 fecal coliforms per 100 ml and some 10^3 helminth eggs per liter where helminth infections are prevalent [26]. Fecal coliform numbers was 1400 MPN /100 mL for the CEPT effluent (Table 3). Removal of bacteria may involve adsorption on the solid particles during the flocculation/sedimentation process. Although could reduce fecal coliform, yet the achievement numbers remained higher than 1000 MPN/100mL, which does not meet the WHO guideline. 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 1400 MNP/100 mL of FC is still too large for the reuse of treated wastewater. Risk associated with reuse is directly related to ingestion and contact with the human body. Precautionary measures could be recommended for reducing the contact between reclaimed water and the irrigator such as, irrigation method (inc. drip, trickle and bubbler irrigation) and stopping irrigation before harvest (1-2 weeks). Need for effective but affordable disinfecting treatment is of paramount importance [14]. However, CEPT is meeting the WHO guideline (2006) for FC which is 1000 MPN/100mL.

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-} (Table 3), which are 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.

CONCLUSIONS

This study showed that the combination of cement kiln dust with a cationic polymer exerts a good effect on the removal of organic matter and other pollutants from municipal wastewater. Treated wastewater by (CKD + PAM) can be considered as entirely safe for irrigation purpose because of its medium salinity and low sodicity as well as low heavy metals Chemicals cost to treat one cubic meter of wastewater was low \$ 0.05 m^{-3}. Thus, CEPT (CKD + PAM) can be used as a simple low-cost technology for municipal wastewater treatment and it's improving the efficiency of cement kiln dust disposal.

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