Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 6(5): 360- 370

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Economic Viability of Removal of Heavy Metal Cations from Industrial Wastewater Using Innovative Technique

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Abstract
Cement Kiln Dust (CKD) is experimented in dynamic up-flow fixed bed reactors using stainless steel columns to study the dynamic breakthrough patterns. Synthetic metal solutes containing the target metals (lead, copper, and cadmium) are fed with an initial concentration of 30 mg/l. The experimental runs show that the CKD has a high affinity to adsorb the target metals. The surface concentration at exhaustion in a molar basis is found to be 240 µM/g, 290 µM/g, and 650µM/g for lead, copper and cadmium, respectively. A pilot scale of 20~25 l/hr capacity is fabricated to investigate the capability of CKD in treating industrial wastewater. Raw industrial wastewater from glass manufacturing is introduced to the pilot scale unit. The proposed treatment unit using CKD is able to reduce the total suspended solids (TSS) by 95% and biological oxygen demand (BOD) by 72%. Moreover, heavy metals concentrations in the raw wastewater have been effectively treated to comply with international guidelines for restricted irrigation. The results are promising and indicating that the introduced methodology can be industrially applied. Finally, the economic indicators in terms of economic rate of return (11.5%) and the positive net economic present value prove that the system is economically viable. Accordingly, it is apparent from this study that CKD can be used in an innovative and compact treatment technique to recover industrial wastewater from heavy metals.

Keywords: heavy metals, industrial waste, cement kiln dust (CKD), economic viability, pilot scale

INTRODUCTION

The food and agricultural organization of the United Nations (FAO) and the world health organization (WHO) identify the quality of treated wastewater effluent. The treated wastewater can be used either for restricted or unrestricted irrigation based on the quality of the treated effluent. Restricted irrigation is limited to cereals, trees, and with no public access, while unrestricted irrigation is for eaten uncooked crops (World Bank, 2014). However, irrigating trees and shrubs might be the safest use of treated wastewater. Law 48/1982 and law 93/1962 are the governing laws for water quality management in Egypt. Law 48 sets specific water quality standards for discharging into underground reservoir, Nile stream, and drains. Law 93 identifies the quality of discharge to sewer systems. The latter has been amended by the Ministerial Decree 44/2000 (by the Ministry of Housing, Utility, and Urban Communities) to distinguish the water quality requirements for unrestricted and restricted irrigation. All involved ministries and agencies should recognize the wastewater quality inspection and regulatory development follow the Ministerial Decree 44/2000 to initiate restricted irrigation for the safe use of wastewater on selected crops (USAID, 2000). Accordingly, mitigating contaminated wastewater influents from domestic or industrial activities is mandatory (Abdelmoez *et.al.*, 2013).

Wastewater containing heavy metal constituents is mainly generated from industrial processes, such as electric battery manufacturing and glass industry (Santos *et.al.*, 2014; Cartier *et.al.*, 2012). In glass manufacturing, lead oxide, potash, zinc oxide, and other metal oxides are used as coloring or de-coloring agents. Accordingly, liquid effluents resulted from grinding, polishing, coating and electroplating processes include suspended solids, heavy metals (i.e., lead), and variations in pH (USEPA, 2014; IFC, 2007). Common techniques used in heavy metals treatment processes are chemical treatment, flotation, filter coalescence, and membrane filtration (Abdelmoeaz *et.al.*, 2013). Application of metal treatment by adsorption in fixed bed reactors using cement kiln dust has not been previously investigated extensively, to the authors' knowledge. Recent studies have been conducted to use CKD to treat wastewater in a batch equilibrium approach (El Zayat *et. al.*, 2014; Mackie *et. al.*, 2010; El

Awady, 1997). Other metal adsorbents have successfully exhibited the potential for heavy metal uptake in fixed bed mode, such as biomass (Carpio *et. al.*, 2014) citrus maxima peel, fruit shells, and sugarcane bagasse (Chao *et. al.,* 2014), and recycled iron (Smith, 1998).

The costs of the present methods of wastewater treatment are increasing rapidly and without beneficial economic return. Moreover, the development and implementation of wastewater collection and treatment schemes to serve the majority of urban populations are receiving increasing priority in most countries, even in developing ones. Moreover, CKD has not been studied comprehensively for its effect on removing heavy metal constituents from wastewater. Accordingly, the problem statement or the guiding research question is: how can high quality treated wastewater be produced free from heavy metals and in compliance with the Egyptian laws and international guidelines using a sustainable solution.

The main objective of this study is to fabricate an innovative technique on a pilot scale wastewater treatment unit comprising primary, secondary, and tertiary treatment. This is to simulate and test the whole industrial wastewater treatment process for heavy metals and organics removal. Primary treatment is used in order to remove suspended solids using settling tanks. CKD column reactors act as a secondary treatment process. The reactors are used to adsorb heavy metals and improve the physiochemical constituents. While tertiary treatment is used to remove micro pollutants and soluble particles using sand filtration and ultra violet (Rattier *et. al.*, 2014; Perez *et. al.,* 2010). The aim of this pilot scale is to introduce new, scalable, and economic treatment system for industrial wastewater; particularly heavy metals removal. The economic indicators based on the net economic present value (NEPV) and economic rate of return (ERR) are also evaluated to investigate the feasibility of the innovative system.

EXPERIMENTAL METHODS

Materials

Cement Kiln Dust

CKD samples are obtained from local cement manufacturing plant in Upper Egypt. The utilized CKD has a particle size of approximately 74 microns and surface area of approximately 4,000 cm^2/gm. The Ca content in CKD is 55.30% by weight.

Synthetic Heavy Metal Solution

The synthetic heavy metal solutions used in the column studies are prepared using reagent grades following the standard methods released by Perkin Elmer (Elmer, 1995). The desired concentrations of the target heavy metals are prepared by diluting the stock solutions in deionized distilled water (DDW). The stock solutions are MERCK type grade, and are used in preparation of both the heavy metal solutions and standards. An ionic background, sodium nitrate ($NaNO_3$) with assay of 99% (manufactured in UK by Gain land Chemical Company GCC, reagent grade), is added. The sodium nitrate is added to the heavy metal solutions to adjust the ionic background to 0.01 M and to ensure the same total dissolved solids concentration in all cases.

Raw Industrial Wastewater Influents

Raw industrial wastewater samples from glass industry are collected and tested in the proposed treatment unit. The characteristics of the raw samples are shown in Table 1.

Column Studies

Adsorption of heavy metals, namely Pb, Cd and Cu using CKD has been previously investigated in batch equilibrium experiments (El Zayat *et. al.,* 2014). CKD demonstrates high potential to adsorb heavy metals up to 90% removal efficiency, even at pH values less than the pHzpc (zero point of charge). Metal removal is a result of electrostatic interactions in addition to surface complexation (El Zayat *et. al.,* 2014). In this study, adsorption of heavy metals using CKD in dynamic fixed-bed reactors is investigated. The used column has an internal diameter of 7 mm and 80 mm length. The column is packed by CKD and supported by fine stainless steel mesh screen and glass beads from top and bottom as shown in Figure 1. For uniform packing, a glass rod is used for tapping and tamping the column. Feed solution containing the synthetic target heavy metals initial concentration (30 mg/l), pH (5.5), and ionic background strength (0.01 M) is continuously mixed in a storage reservoir with a tight cover. Effluent from the reservoir is pumped to the column by a positive displacement pump that delivers the solution in up flow mode to the column at a rate of 6ml/min. At the bottom of the column there is a three-way valve that directs the influent either to the column or to waste. The experimental setup is shown in

Figure **1**.

Both influent and effluent samples are collected at frequent intervals to obtain the relative concentration breakthrough profiles for the solutes. The purpose of the column study is to observe the adsorption kinetics of the solutes and dynamic breakthrough patterns.

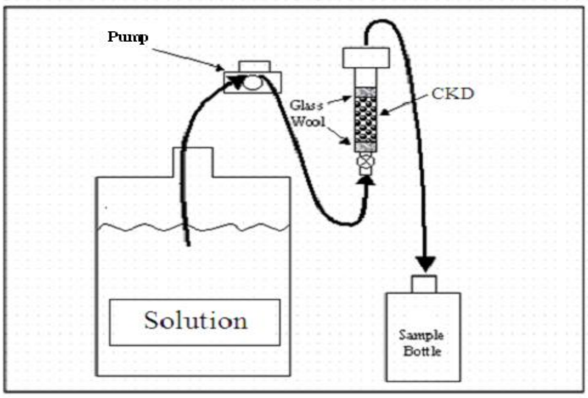

Figure 1: The Column Experiment Setup

Design of Pilot Scale Wastewater Treatment Plant

A pilot scale wastewater treatment plant with 20 to 25 L/hr capacity, comprising primary, secondary and tertiary treatment, is designed and fabricated based on the obtained results from the bench scale experiments results. The design is based on the operating conditions resulting from the bench scale experiments and the previously performed isotherm modeling (El Zayat *et. al.,* 2014). Table 1 shows the equations, assumptions, and specifications that are used to identify the dimension of the different treatment units.

Pilot Scale Unit Description

The pilot scale wastewater treatment plant comprises three stages; primary, secondary, and tertiary. The primary treatment unit consists of coagulation tank, flocculation tank, settling tank, and sand filtration. The secondary treatment unit consists of the heavy metals removal reactors using CKD. The tertiary treatment consists of sand filtration together with activated carbon and Ultra Violet (UV) unit. Moreover, the pilot unit is equipped with the following auxiliary items: influent storage tank, effluent storage tank, collection sampling tanks for each treatment stage, displacement pumps and mixers, electrical control panel, pipes, valves …etc.

The unit is fabricated from transparent poly acrylic material to better monitor and to observe the treatment processes. Figure 2 shows the pilot scale setup.

Table 1: Equations and Assumptions used for the Design of the Pilot Scale

Primary Treatment Process	
Coagulation Tank Design	$\boldsymbol{V = QT}$ Where *V* is volume (L), *Q* is flow rate (L/hr), *T* is the detention time (hr). The used paddle is a vertical-shaft paddle mixer, and then the detention time can be assumed between 10 to 30 minutes (Mihelcic, 2010). Therefore tank dimensions are calculated as L= 10 cm, W = 15 cm, H= 25 cm
Flocculator	The same as the coagulation tank, the volume of the flocculation tank can be determined from $\boldsymbol{V = QT}$ Detention time is assumed to be 0.5 hrs. Therefore tank dimensions are: L= 15 cm, W = 40 cm, H= 25 cm.
Settling Tank	**V = QT** Assuming the V = 35 L (20 cm x 50cm x 35 cm). Therefore, T = 1.75 hrs. Determining the critical particle settling velocity: $\boldsymbol{V_c = \frac{Q}{A}}$ Therefore, V_c= 0.2 cm/hr. The settling tank is equipped with five lamella settlers to enhance the removal of the suspended solids and colloids.
Filter Design	**A = Q/F** Where, *A* is the area in m^2, *Q* is the flow rate m^3/hr, *F* is the filtration rate m^3/ m^2.hr; Rapid sand filtration gravity type is employed. Assuming F = 3 m^3/ m^2.hr and Q = 20 L/hr. Therefore, D= 10 cm and L = 3 D = 30 cm. The Filter media is uniform in size to allow the filter to operate properly. Also, the sand is washed before starting the treatment process. The uniformity coefficient (UC) [d_{60}/d_{10}] was approximately 1.5.
Secondary Treatment Unit (CKD Reactors)	

CKD Reactors	Two types of tanks are used. The first type is cylindrical tanks with stirrer (batch type) and the second one is fixed bed cylindrical columns. The capacity of each tank is approximately 2.5 L.
Tertiary Treatment Unit	
Sand Filtration	A tank with a cylindrical shape with 10 cm diameter and 30 cm height is used.
Ultra Violet (UV) Lamp	The ultraviolet (UV) has an electromagnetic radiation having a wavelength between 100 and 400 nm.

Figure 2: The Pilot Scale Setup

Pilot Scale Process Description

Raw industrial wastewater samples from glass industry are collected and tested in the proposed wastewater treatment pilot scale unit. Figure 3 shows the processes block diagram and Figure 4 shows the process flow chart. The raw wastewater is conveyed from the intake tank to the primary treatment tank (settling tanks) to remove any large particles. The effluent then is discharged by gravity to a sand filter to remove any suspended colloids and solids. The filtrate is then fed to the heavy metals removal tanks. In the fixed bed reactor, approximately 500 gm CKD is poured in the reactor. In the stirrer tanks, 2 gm/l of CKD is added during the experimental runs and mixed at high speed. The wastewater effluent passes through a carbon sand filter to remove some of the suspended CKD particulate as well as any odor nuisance. Also, the carbon sand filter acts as a final bleaching stage. The treated industrial wastewater finally passes through a UV lamp unit and then to storage tanks. The UV lamp is used in order to destroy any pathogens or bacteria that can be found in the treated wastewater. A sample is collected after each treatment process and analyzed to determine the efficiency of each treatment process. All pumps and the stirrer of the mixer tanks are controlled through an electrical control panel.

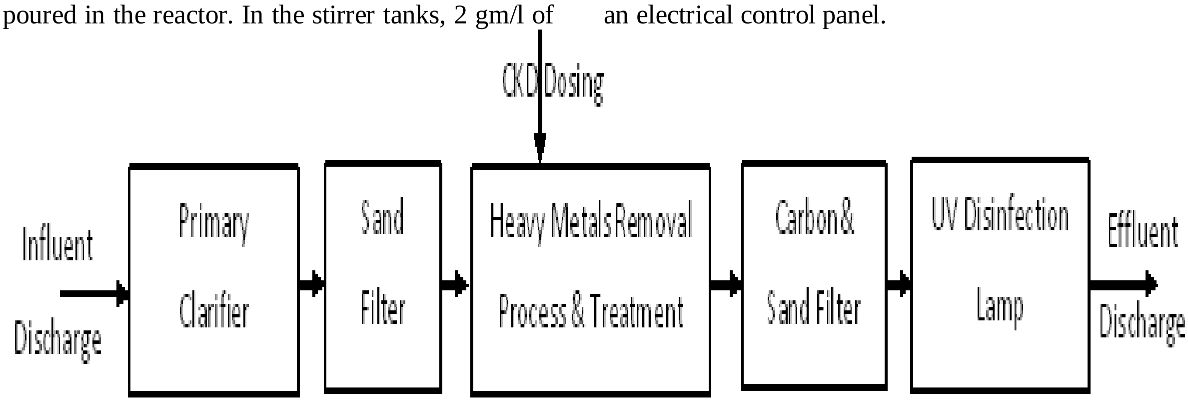

Figure 3: Treatment Processes Block Diagram

Economic Analysis

The economic viability entails analyzing the data using shadow process as to eliminate price distortion, analyze the indirect costs and benefits of the proposed project, and look at the overall effect of the project on the economy. The payback period (PBP), economic rate of return (ERR), and net economic present value (NEPV) are the economic indicators used to evaluate the project. Equation 1 is used to calculate the PBP from an investment. To be used in the study, it is required to estimate the initial capital costs and expected yearly profits.

$$Pay\ Back\ Period\,(Years) = \frac{Initial\ Capital\ Cost(USD)}{\Pr ofits\,(USD/Year)} \quad \textbf{(1)}$$

The ERR is the discount rate that will equate the NEPV of the economic benefit (EB) and economic cost (EC). NEPV is calculated using Equation 2.

$$NEPV = -C_o + \sum_{i=1}^{T} \frac{NCF_i}{(1+SDR)^i} \qquad \textbf{(2)}$$

In equation 2, the C_o is the initial investment which is a negative cash flow. The NCF_i is the net cash flow for year *i* while SDR is the social discount rate. The next step in completing the economic study is to estimate the initial capital cost for the treatment system. The capital cost for any wastewater treatment facility depends on many factors and parameters, such as equipment cost, installation, piping, instrumentation and controls, and engineering.

Table **2** shows the standard capital cost algorithm according to USEPA (USEPA, 2014). The EPA also states that 4% of the total capital cost is required for annual maintenance.

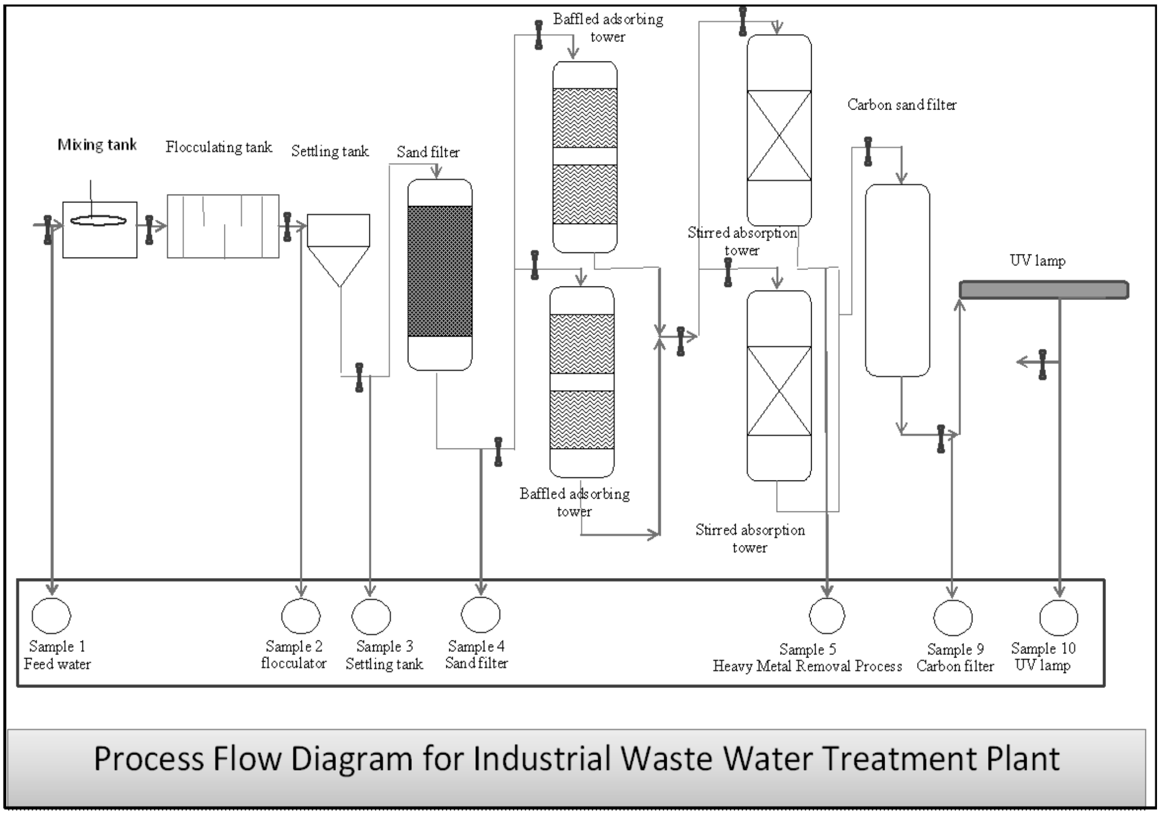

Figure 4: Treatment Process Flow Chart

Table 2: Standard Capital Cost Algorithm (USEPA, 2014)

Factor	**Capital Cost**
Equipment Cost	Technology – Specific Cost
Installation	25 to 55 percent of Equipment Cost
Piping	31 to 66 percent of Equipment Cost
Instrumentation and Controls	6 to 30 percent of Equipment Cost
Total Construction Cost	***Equipment +Installation +Piping Instrumentation and Controls***
Engineering	15 Percent of Total Construction Cost
Contingency	15 Percent of Total Construction Cost
Total Indirect Cost	***Engineering + Contingency***
Total Capital Cost	**Total Construction Cost + Total Indirect Cost**

The USEPA guidelines for identifying the cost of the treatment technology are used (USEPA, 2014). The guidelines provide a general description of how EPA developed costs for the different individual treatment technology and the development of costs for each of the wastewater and sludge treatment technologies evaluated. Equation 3 mentioned in the EPA guidelines, is used to estimate the capital cost for the secondary precipitation system in the model technology for metals.

$$\ln(Y1) = 13.829 + 0.544\ln(X) + 0.0(\qquad \textbf{(3)}$$

Where *Y1* is the capital cost in USD and *X* is the daily flow rate in Million Gallons.

This secondary chemical precipitation equipment consists of a single mixed reaction tank with pumps and a treatment chemical feed system, which is sized for the full daily volume. This treatment technology is equivalent to the proposed treatment facility. EPA calculated capital cost estimates for the secondary precipitation treatment systems from vendor quotations. These costs include the cost of the mixed reaction tanks with pumps and treatment chemical feed systems. The total construction cost estimates include installation, piping and instrumentation, and controls. The total capital cost includes engineering and contingency at a percentage of the total construction cost plus the total construction cost as explained in

Table **2**. For the facilities that have at least primary chemical precipitation in-place, EPA assumes that the capital cost for the secondary precipitation treatment system would be zero. The in-place primary chemical precipitation systems would serve as secondary precipitation systems after the installation of selective metals precipitation units.

Unlike the financial feasibility studies where the rate of return is compared to the weighted average cost of capital (WACC), the ERR is compared with the social discount rate in order to know whether the project is viable or not. The social discount rate is the rate at which the value placed by society on future benefits and costs declines over time. The social discount rate reflects the social opportunity cost of capital, so that it provides the link between costs and benefits occurring at different time. According to the UN-ECLAC (2011), little consensus exists on the choice of an appropriate SDR (UN-ECLAC, 2011). A significant interest rate variation of 8-15% is reported by developing countries. Ministry of finance in its info memorandum report for 6th of October Wastewater Treatment Plant (WWTP) in 2009 reported that the central bank of Egypt (CBE) discount rate averaged 10% in 2008, and observed short-term lending and deposit rates are in the range of 12.2% and 6.1% respectively in 2008. Since no risk premium is anticipated in this analysis, 8% interest rate is used as a reasonable social discount rate. The estimation of no risk premium is based on that sustainable and environmentally friendly infrastructure projects are social capital projects. Moreover, the proposed project aims at alleviating a health risk issue from both CKD and industrial wastewater.

RESULTS AND DISCUSSION

Column Studies

The bed volume is a measure of the volume of water that passed through the packed column of CKD. In order to have a meaningful comparison, the effluent concentrations should be compared with the bed volumes rather than run time. This is because of the variable flow rates and run times. The bed volume is calculated as per Equation 4.

$$Bed\ Volumes = \frac{Volume\ treated}{Volume\ of\ Packed\ CKD} = \frac{flowrate(ml/\min)*time(\min)}{Volume\ of\ packed\ Column} \quad \textbf{(4)}$$

The breakthrough curve as a function of C_{eff}/C_o versus CKD bed volumes for the three target heavy metals is shown in Figure 5 through Figure 7. It is observed that the maximum breakthrough occurs beyond 2,496 bed volumes for the three metals where C_{eff}/C_o is on the increase until the end of the experiment. It is also obvious that C_{eff} reached more than 80% of the value of C_0 after just 4 hours. A complete CKD exhaustion can be observed after 8 hrs. Calculation of surface concentration at the termination of the run is performed using Equations 5 to 8.

$$M_{\text{passing}} = (F \times t_f \times 60 \times C_0) \quad \textbf{(5)}$$

$$\frac{M_{\text{ads}}}{M_{\text{passing}}} = \frac{A}{A+B} \quad \textbf{(6)}$$

$$M_{\text{ads}} = \frac{A}{A+B} x M_{\text{passing}} \quad \textbf{(7)}$$

Surface concentration at exhaustion =

$$\frac{M_{\text{ads}}}{Mass\ of\ CKD\ in\ Column} \quad \textbf{(8)}$$

Where M_{passing} is mass of metal passing through the column (mg), M_{ads}= Mass of metal adsorbed by the CKD (mg), F= Volumetric metal solution flow rate through the column (0.006 L/min),t_f= Total time of the column run until exhaustion (8 hrs), C_0= Influent Concentration of metal (30 mg/l), A= Area representing the adsorbed portion, and B=Area representing the un-adsorbed portion. A and B are calculated using a grid method to know the area under the curve.

The empty bed contact time (EBCT) and hydraulic rating rate are calculated in order to determine the required time for wastewater recovery based on the bed volume size. The EBCT is considered an important factor for designing the bed column as it has a significant impact on the performance of the packed CKD. In order to produce treated wastewater with acceptable quality, the depth of packed column and its corresponding minimum EBCT should be considered (Louis, 2006). As EBCT increases, the bed life will increase until a maximum value is reached. Accordingly, longer EBCT is applied for industrial wastewater effluents (Mondal *et.al.*, 2008).The EBCT is a measure of how much time a parcel of fluid spends in the column, on the basis that the column contains no packing. Therefore, the EBCT is simply the column volume (mL) divided by the volumetric flow rate of the liquid (mL/min). The EBCT depends on the column bed height. The longer is the bed height the longer is the EBCT (Sun *et.al.*, 2014). Practically, designers often like to work with hydraulic loading rate which is the liquid flow rates expressed in terms of the hydraulic loading (H) in $L^3/t.L^2$ or L/t. This is because it based on the cross sectional area of the column. The EBCT is calculated using Equation 9.

$$EBCT=\frac{V}{Q}=\frac{L_{bed}}{Q/A} \qquad (9)$$

Where *V* is the column volume which is the column area multiplied by the packed CKD length in the column= $\pi r^2 x$ L = 1.1540 cm^3. The Hydraulic Loading Rate (HLR) is the Design Flow /Cross Sectional Area. Therefore, the HLR=15.6 cm/min

The results of the column experiments for the three target metals are shown in Table **3**.

Table 3: Analysis of the Column Experiment for Heavy Metals Removal

Parameter	Unit	Value		
		Lead	**Copper**	**Cadmium**
Breakthrough Bed Volumes		2,496	2,496	2500
Surface Concentration At Exhaustion	mg M^{2+}/g CKD	49	18.4	73
	μM/g (molar basis)	240	290	650
Hydraulic Loading Rate (HLR)	cm/min	15.6		
Empty Bed Contact Time (EBCT)	Min	0.20		

Pilot Scale Runs

The designed pilot scale is used to treat industrial wastewater effluent from glass manufacturing. The influent and effluent samples are analyzed not only for heavy metals but also for all other physiochemical parameters. The treated industrial wastewater results are in compliance with the Egyptian regulations (decree 44/2000) and international standards (FAO, 1985) as shown in Table 4, and hence can be used for landscape irrigation, for instance. The proposed unit is able to reduce the physiochemical constituents in terms of TSS and BOD by 95% and 72%; respectively. A significant improvement in the heavy metals uptake is noticed. For instance, the lead concentration has been reduced from 31.5 mg/l to 0.242 mg/l.

Table **4** shows the sampling and results of the pilot scale experimental runs. It is found that the designed system is able to significantly recover the industrial wastewater from heavy metals as well as the physiochemical parameters, such as Total Suspended Solids (TSS), Chemical Oxygen demand (COD), and Biological Oxygen Demand (BOD). There is only slight increase in the pH of the wastewater especially after passing through the heavy metal removal unit. This is attributed to the alkalinity of the cement kiln dust.

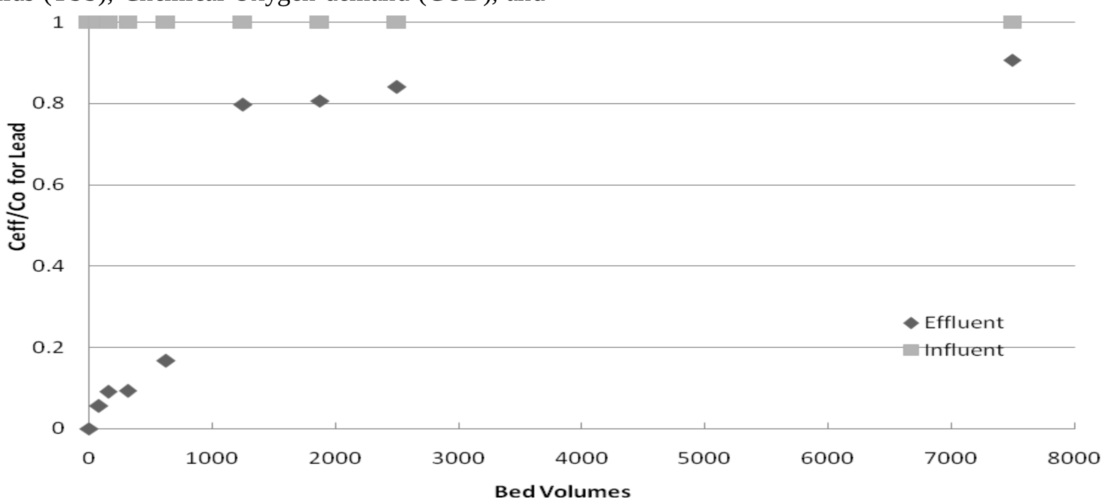

Figure 5: Breakthrough Curve of Pb versus Bed volumes

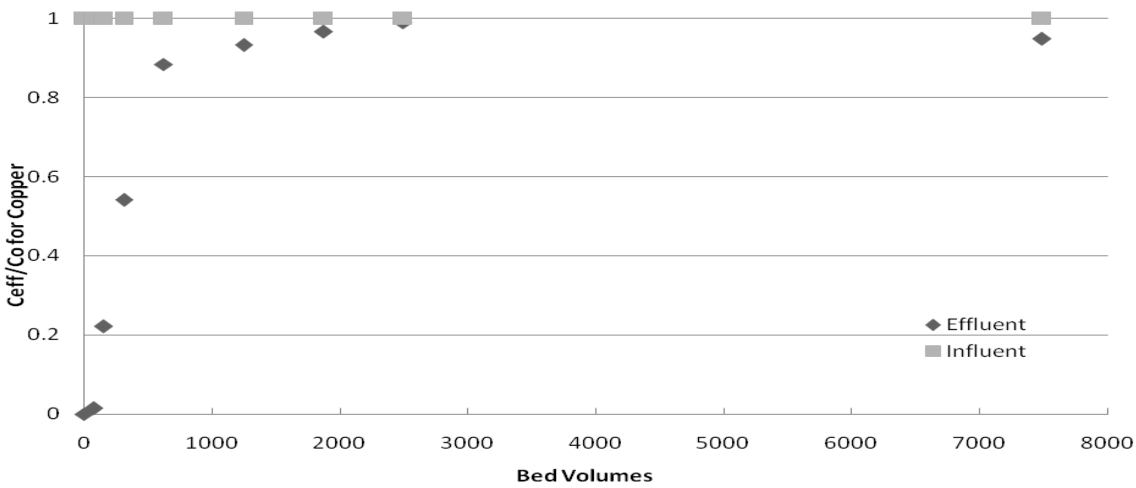

Figure 6: Breakthrough Curve of Cu versus Bed Volumes

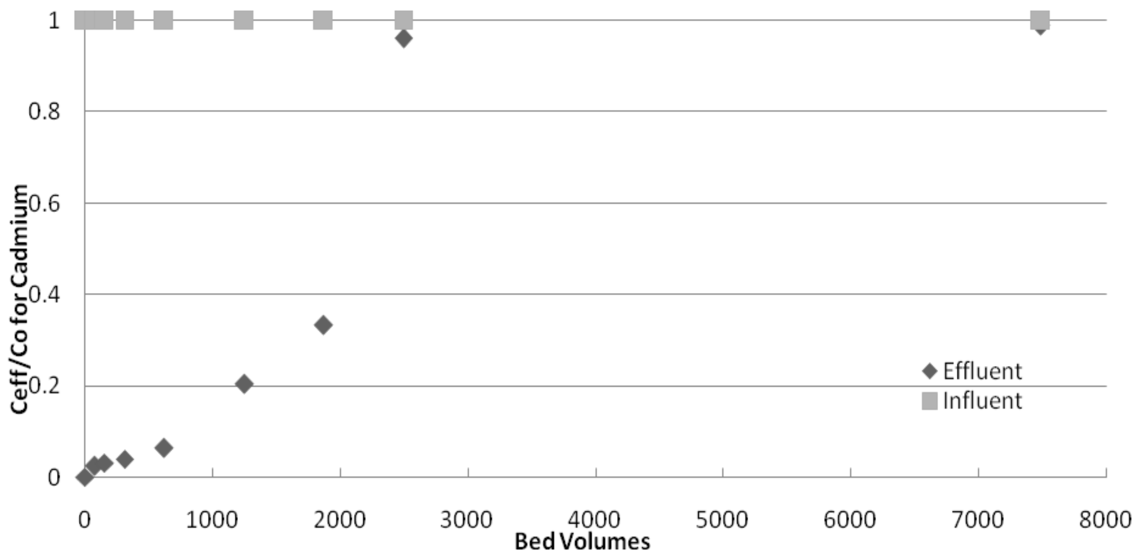

Figure 7: Breakthrough Curve of Cd versus Bed Volumes

Table 4: Pilot Scale Sampling Analyses

	Parameter	Unit	Raw Sample	After settling tank	After CKD reactor	After Sand Filtration +UV	Egyptian Allowable Limits (Decree 44/2000)	International Standards*
	pH	-	8.42	8.42	9.6	9.96	6-10	6-9
	TSS	mg/l	442	154	44	24	40	50
	COD	mg/l	127		76	79	80	150
	BOD	mg/l	99		25.7	28	40	50
Heavy Metals	**Lead (Pb)**	mg/l	31.5	30.1	1.0	0.242	5	5
	Copper (Cu)	mg/l	0.566	0.464	0.094	0.074	0.2	0.2
	Chromium Total (Cr)	mg/l	0.139	0.121	0.082	0.074	ND**	0.1
	Cobalt (Co)	mg/l	0.125	0.118	0.048	0.01	0.05	10
	Nickel (Ni)	mg/l	0.70	0.653	0.057	0.039	0.2	0.2
	Iron (Fe)	mg/l	0.586	0.553	0.88	0.115	5	5
	Zink (Zn)	mg/l	1.152	1.137	0.038	0.012	2	2

** Food and Agricultural Organization of the United Nations (FAO), 1985*
***ND: Not Determined*

Economic Viability

WWTP Sizing for Economic Analysis

In order to complete the economic feasibility study, the pilot scale WWTP is sized so that it would be suitable for treating full scale industrial wastewater of minimum capacity 1,000 m^3/day. From the assumptions outlined in the previous section, the yearly feed loading requirements are calculated. Accordingly, the total input to full scale system is 365,000 m^3/year. Therefore, the amount of CKD needed to treat this amount of industrial wastewater is 2 tones daily (730 t/year) in case of batch treatment as previously depicted (El Zayat *et. al.,* 2014). Much less amounts of CKD can be utilized in case of using column adsorption towers. This depends on the breakthrough of the CKD in treating the industrial wastewater. From the bench scale experiments, 250 kg CKD are required to treat 1,000 m^3. Therefore, the required amount of CKD in case of using column adsorption towers is 0.25 tones daily (91.25 t/year).

Economic Analysis

The economic feasibility study is completed in U.S. Dollars which required conversion of Egyptian pounds to U.S.Dollars without distortions. Hagag, 2012 identified the shadow exchange rate from 2007 to 2010 using the supply and demand approach which is based on the ratio between capital and goods inflows and outflows (Hagag, 2012). The shadow exchange rate (SER) from 2010 to 2016 has been also anticipated on an annual devaluation value of 3%. The SER varies from 6.7 up to 8.2 EGP. Based on the current exchange rate and the SER, using 7.30 EGP seems a reasonable value for the current study. The exhausted CKD for the treatment process can be used in other industrial processes, such as ceramics and brick productions (Al Awady, 1997). Therefore, the traded product from the plant is the treated effluents assuming that the CKD that could be used in other process facilities has no value as a conservative approach. Comparing the proposed system to conventional systems, the proposed system will conserve all the energy requirements for aerobic tanks and blowers. Therefore, the proposed system will have another economic value from energy savings point of view. The energy savings are calculated based on the shadow price of the national electricity. The electricity tariff depends on the amount of monthly consumption. The national tariff of electricity increases if the consumption rate increases. The amount of saved electricity from the proposed system is estimated to be 2.5 kwh/m^3 which is the required energy for the conventional aerobic wastewater process. Therefore, the annual energy savings is approximately 913MWh. Accordingly, the equivalent commercial tariff category of 0.58 EGP/ kwh is applied. According to the African Development Bank report “Reforming Energy Subsidies in Egypt”, the subsidy rate of electricity is estimated to be 44% (Hagag, 2012). The average international price of treated effluent wastewater that could be used for irrigation purposes in the Mediterranean is 0.23 Euro/m^3 (Chartzoulakis *et. al.,* 2001). Using the international exchange rate for Euro and U.S. Dollar (XE, 2014), the price of treated wastewater will be 0.32 USD/ m^3. The next step in completing the economic study was to estimate the initial capital cost for the treatment system. Equation 3 was used to estimate the initial capital cost. Since the flow rate is 1,000 m^3/day, it was calculated that the capital cost is 491,000 USD.

Economic Indicators

The economic analysis was performed on a life time period of 10 years. Using the yearly operating costs and income from reusing the treated wastewater effluents as a basis, the estimated yearly profits are calculated. The yearly profits and the initial capital costs are then used to calculate the expected payback period (PBP) using Equation 1. The ERR and the NEPV are computed using Equation 2. Table 5 shows the economic indicators. In addition to the economic indicators, economic contribution or indirect effects of the treatment facility will be measured in terms of value added, employment, and foreign exchange earnings. The value added is a major economic indicator to explain to what extent the project is valuable. By subtracting the transfer abroad from the domestic value added, we can obtain the national value added. The domestic value added is measured as the difference between the gross output (i.e., wages, net benefits…) and the material inputs. The gross output of the treatment system exceeds the material inputs. The domestic value added is equal to the national value added as the transfer abroad is zero. Therefore, the value added is a significant positive value. The project leads to employment generation where more employees will be required to maintain the new project. The new job roles generated by the project will bring about a more technically savvy pool of laborers. The project is projected to save electricity as one of the important inputs to any treatment facility. In addition, it will produce a tradable product which is clean water for irrigation use. By comparing the ERR to the SDR at 8%, it is obvious that the project is economically viable. In addition to the ERR, the NEPV is positive. However, we can conclude that implementing the proposed treatment system in Egypt is economically viable taking into consideration the economic contributions and indirect benefits.

Table 5: Economic Analysis Indicators

Item	Cost
Outcome(USD/year)	
Initial Capital Cost	491,000
Maintenance	19,640
Income(USD/year)	
Electricity Savings	104,400
Treated Effluents	320

Economic Indicators	
Economic Rate of Return (ERR) (%)	11.5
Pay Back Period (years)	5.7
NEPV (USD)	79,894

CONCLUSIONS

- The column tests show that the CKD has a high affinity to adsorb the target heavy metals from the aqueous solutions.
- The column reactors have higher adsorption capacity than the batch ones for the same initial concentration of adsorbate. This is due to the fact that the driving force throughout the column run is higher with respect to the liquid phase concentration of the solute.
- The pilot scale industrial wastewater treatment plant is successfully able to treat an industrial wastewater generated from glass manufacture from any heavy metals or physiochemical constitutes. Heavy metal removal efficiency reached 99% while physiochemical constituents in terms of TSS and BOD reached 95% and 72%; respectively. The pilot scale is able to produce treated effluent with high quality in compliance with the international and national guidelines.
- The treated effluent can be used directly for irrigation purposes according to Egyptian regulations (decree 44/2000) and international standards (FAO, 1985).
- The economic analysis showed that the proposed project is economically viable (ERR 11.5%). Thus, it will help contribute to the sustainable development of Egypt through its contribution to the environmental, economic, and social pillars.
- The project has positive value added, and will create job opportunities.
- The project showcases an innovative way to use cement kiln dust as an industrial waste in treating wastewater to produce treated effluents.

ACKNOWLEDGEMENTS

Financial support for this work was provided by the Academy of Scientific Research and Technology (ASRT) Cairo, Egypt. Help from Dr. Wael Abdelmoez (R&D TECH, El Minya University) is acknowledged. Any opinions, findings, conclusions or recommendations expressed in this work are those of authors and do not reflect the view of supporting organization.

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