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KINETIC MODELING OF DESORPTION OF CADMIUM (II) ION FROM MERCAPTOACETIC ACID MODIFIED AND UNMODIFIED AGRICULTURAL ADSORBENTS

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ABSTRACT

The desorption kinetics of cadmium (II) ion from mercaptoacetic acid modified and unmodified agricultural adsorbents following an adsorption experiment was studied using five different desorbents At the end of 25 minutes contact time, the desorption efficiency followed the trend; 0.1M HCl > 0.1M H_2SO_4 > 0.1MHNO_3 > 0.1M NaOH > hot deionized H_2O for all three adsorbents (UOPF, 0.5 MOPF and 1.0MOPF). Kinetic modeling of Cd^{2+} desorption using Elovich and pseudo-first order desorption equations indicated that the pseudo-first order equation better described Cd^{2+} desorption from the surface of each adsorbent The desorption rate constant, β for 0.1M HCl were; 6.57 x 10^{-1}, 4.43 X 10^{-1}, and 3.98 x10^{-1}mg.g^{-1}.min^{-1} for UOPF, 0.5MOPF and 1.0MOPF adsorbents respectively. While surface residence time, τ values for 0.1M HCl were: 31.4, 33.8 and 30.72 seconds for UOPF, 0.5MOPF and 1.0MOPF adsorbents respectively.

KEYNOTES: Desorption, Elovich, pseudo-first order, oil palm.

INTRODUCTION

The suitability of any wastewater treatment for heavy metals must involve the cost implication of the process and the nature of disposal of the resulting waste arising from the treatment. Chemical wastewater treatment technologies like precipitation, reverse osmosis, electrode-deposition and cementation do have some limitations due to the formation of sludge which leads to a solid waste disposal problem and the high cost of the process. The need for economical and efficient methods for removing heavy metals from wastewater has resulted in the search for unconventional materials that may be useful in reducing the values of accumulation of these pollutants in the environment. (Okieimen *et al.*, 1991).

This has resulted in the application of adsorption using agricultural waste products for the removal of metals from various effluent streams. One of the toxic heavy metals of interest to environmentalist is cadmium. This divalent metal has no known biological function but exerts its toxicity by accumulating in the food chain (Cordero *et al*, 2004).

Various studies have been carried out to determine the effectiveness of adsorption using agricultural waste products for the treatment of heavy metal ions (Okieimen *et al*, 1988; Ho *et al.*, 2002, Eromosele and Otitolaye, 1994; Igwe and Abia, 2003 and Igwe *et al.* 2005).

To further enhance the suitability of adsorption process for the treatment of wastewater polluted with heavy metals using agricultural byproducts, it is necessary that a method of recovery of the adsorbent used for sorption of the target metal be designed. The desorption of spent adsorbents used for the removal of metal ions helps to regenerate the metal-loaded adsorbent and this makes the overall adsorption-desorption process very economical.

In this direction a number of studies on the desorption of metals from used adsorbents using various solutions like HNO_3, H_2SO_4, HCl and NaOH have been reported (Arpa *et al*, 2000; Fraile *et al*; 2005; Horsfall et al., 2003; Krishnan, and Anirudhan, 2003 and Wankasi *et, al.* 2002).

In a recent study an agricultural waste product; oil palm fruit fibre (*Elaeis guineensis*) was used as an adsorbent to remove cadmium (II) ion from aqueous solutions and wastewater (Asuquo, 2005). This present study highlights the kinetics of the desorption of Cd^{2+} ion from the metal-loaded oil palm fruit fibre adsorbent using a range of desorbing solutions.

MATERIALS AND METHODS

Adsorbent Preparation

The oil palm fruit fibre was obtained from an oil mill in a village near Uyo, Akwa Ibom State of Nigeria. The fibre was de-oiled by soaking in hot deionized water and detergent for 24 hours. It was further rinsed in hot deionized water and air dried for 12 hours. The air-dried oil palm fruit fibre was ground using a National electric blender. The ground fibre was screened through a set of sieves of sizes (250μm, 150μm and 106 μm) with the resulting fibre from the 106 μm sieve used.

The sieved adsorbent was divided into 3 parts each weighing 200g. The first part labeled "1" was left untreated and called "unmodified oil palm fruit fibre" [UOPF]. 200g of each of the second and third parts labeled "2" and "3" respectively were acid treated with 0.5M mercaptoacetic acid and 1.0M mercaptoacetic acid ($HSCH_2COOH$) for 30 minutes. Each of the suspensions was left to stand for 24 hours at 28°C. Thereafter the two portions were filtered using Whatman No 41 filter paper. The residue in each filter paper was rinsed with deionized water. The residue of the 0.5M acid treated oil palm fruit fibre was labeled "0.5MOPF", while the residue of the 1.0M acid treated adsorbent was labeled "1.0MOPF"

Adsorption Studies

Adsorption studies were first of all carried out using the three adsorbents (UOPF, 0.5MOPF and 1.0MOPF). This was to remove Cd^{2+} from standard aqueous metal solutions of concentrations (10, 20, 30, 40 and 50mg/L) prepared from analytical reagent grade metal salt ($CdCl_2$. 21/2 H_2O) at pH 6.2 and temperature 28°C.

100cm^3 of the metal solutions were placed in various Erlenmeyer flasks and labeled. This was followed by weighing 0.5g of each adsorbent into the differently labeled flasks and each was properly corked. The contents of each flask were agitated on a shaker at 25 rpm for 1 hour before filtration using Whatman No. 41 filter paper. The filtrates were analysed in a UNICAM 919-SOLAR Atomic Absorption spectrophometer for cadmium (II) ions.

Desorption Studies

0.5g of each of the used adsorbents (UOPF, 0.5MOPF and 1.0MOPF) were weighed into different 250cm^3 Erlenmeyer flasks and labeled. The adsorbent in each flask

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was desorbed of the Cd^{2+} by the addition of $100cm^3$ of the various desorbing solutions:
0.1M HCl, 0.1M NaOH, hot deionized water, 0.1M HNO_3 and 0.1M H_2SO_4
The content of each flask was agitated on a shaker at 25rpm for 5, 10, 15, 20, and 25 minutes at temperature of 28°C. After agitation, the contents were filtered using a Whatman No 41 filter paper. $20cm^3$ of each of the filtrates were analysed for the residual concentration for Cd^{2+} using a UNICAM-919-solar Atomic Absorption spectrophotomer. Blank solutions were also prepared and analysed to eliminate errors.

Data Analysis

The metal uptake capacity was calculated using the formula in equation 1 (Ho, 2001) below

$$q_e = \frac{(C_i - C_e)V}{Ms} \quad - \quad 1$$

where q_e is the metal uptake capacity of the adsorbent (mg/g), C_i is the initial metal ion concentration in solution (mg/L), C_e is the equilibrium metal ion concentration in solution (mg/L), Ms is the weight of the adsorbent used for adsorption (g) and V is the value of the initial metal ion used for sorption (dm^3).

From the results of the initial adsorption studies using the three adsorbents, the metal uptake capacity (q_e) for the various adsorbents where: 18.6mg/g (UOPF), 19.96mg/g (0.5MOPF) and 21.70mg/g (1.0MOPF). These metal loading capacities were used for all the desorption studies.

Also, the amount of metal ion removed from the various adsorbents during the desorption studies was computed using the relationship in eqn (2):

$$q_d = q_e \left(\frac{(de)}{M_s}\right) V \quad - \quad - \quad 2$$

where q_d is the metal ion concentration removed from the adsorbent (mg/g) during desorption, q_e is the initial adsorbent metal loading capacity (mg/g), de is the equilibrium metal ion concentration desorbed from the adsorbent (mg/L), V is the volume of the desorbing solution used (dm^3) and Ms is the mass of the loaded adsorbent used for the desorption (g).

In addition, the amount of the metal ion remaining on the adsorbent as a function of time (q_t) was estimated using the relationship in eqn (3):

$$q_t = q_e - q_d \quad - \quad - \quad 3$$

Where, the symbols have the same meaning as previously stated.
Furthermore, the percentage of the metal desorbed from the various adsorbent was computed using the relationship in eqn (4):

$$\% \text{ Desorption} = \frac{q_d \times 100}{q_e} \quad - \quad - \quad 4$$

Kinetic Modeling of Desorption

The kinetics of metal desorption was analysed using two kinetic equations. The Elovich equation (Chien and Clayton, 1980; Sparks, 1986) and the pseudo-first order rate equation (Chu and Hasim, 2001).

The Elovich equation is expressed as eqn 5:

$$\frac{dq_t}{dt} = \alpha \exp(-\beta q_t) \quad - \quad - \quad 5$$

Where α is the initial adsorption rate ($mg.g^{-1}.min^{-1}$), β is the desorption rate constant ($g.mg^{-1}.min^{-1}$) and q_t is the metal adsorbent capacity (mg/g).

To simplify the Elovich equation Chien and Clayton (1980) assumed that $\alpha\beta t >> t$ and by applying the boundary conditions $q_t = 0$ at t=0 and $q_t = q_t$ at t=t. The equation becomes: (Demirbas *et al*, 2004).

$$q_t = \frac{\ln(\alpha\beta)}{\beta} + \frac{\ln t}{\beta} \quad - \quad - \quad - \quad 6$$

Equation (6) was further modified to account for desorption capacity (q_d) by inserting q_d in place of q_t resulting in eqn. (7):

$$q_d = \frac{1}{\beta}\ln(\alpha\beta) + \frac{1}{\beta}\ln t \quad - \quad - \quad - \quad - \quad 7$$

If the desorption rate of the metal from the three adsorbent (UOPF, 0.5MOPF and 1.0MOPF) fits the Elovich equation, a plot of q_d versus lnt should yield a linear relationship from where the slope and intercept can be used to obtain the desorption rate constant (β).

Secondly, the pseudo-first order rate equation for desorption is expressed as equation (8):

$$\frac{q_t}{q_o} = \exp(-K_{des}\, t) \quad - \quad - \quad - \quad 8$$

Where, q_t is the metal concentration in the adsorbent phase (mg/g of adsorbent) at time t (min), q_o is the total desorbable metal concentration on each adsorbent at the beginning of desorption (mg/g adsorbent) and K_{des} is the pseudo-first order desorption rate constant (min^{-1}) (Wankasi *et al*, 2005).

To account for the fraction of bound metal ion resistant to desorption by recovery reagents, equation 8 was modified as follows:

$$\frac{q_t}{q_o} = \theta \exp(-K_{des}\, t) + (1-\theta) \quad - \quad - \quad 9$$

Where θ is a desorption fraction of the initial metal loading (q_e) and (1- θ) is fraction resistant to desorption. Linearising eqn (9) by taking the natural logarithm gives eqn (10)

$$\ln\left(\frac{q_t}{q_o}\right) = (\ln\theta - K_{des})\, t + \ln(1-\theta) \quad - \quad 10$$

From equation (10) a plot of $\ln q_t$ versus q_o time (min) will give a linear graph, if the desorption kinetics follows this model. From which the pseudo-first order desorption rate constant (K_{des}), the desorbable fraction θ and fraction resistant to desorption (1-θ) can be obtained from the slope and intercept of the graph.

RESULT AND DISCUSSION

Kinetic studies on the desorption of cadmium (II) ion from the three adsorbents (UOPF, 0.5MOPF and 1.0MOPF) was carried out using five different solutions. Examination of literature indicates that various organic and inorganic acids and bases have been used for desorption studies.

The percentage desorption of cadmium ion from the three adsorbents using 0.1M HCl, 0.1M NaOH, hot deionized water, 0.1M HNO_3 and 0.1M H_2SO_4 indicates an increase in desorption efficiency with passage of time. Figure 1 presents the percentage of metal ion desorbed for UOPF adsorbent. While Figure 2 is an illustration of the percentage desorption of 0.5MOPF adsorbent and Figure 3 is the removal efficiency for 1.0MOPF adsorbent.

The trend that is observed is that the percentage removal of Cd^{2+} from the UOPF adsorbent was maximum at 25 minutes. From Figure 1, it was seen that 0.1M HCl had the highest desorption efficiency of 78.93%, while hot deionized water had the least efficiency of 23.10% at 25 minutes of desorption. From Figures 2 and 3, the same trend was observed for the 0.5MOPF and 1.0MOPF adsorbents with highest desorption efficiency for 0.5MOPF being 0.1M HCl with 76.65% and the least being hot deionized water of 24.89%. For the 1.0MOPF adsorbent 0.1M HCl had the highest efficiency of 73.87% while the least was 25.39% for hot deionized water.

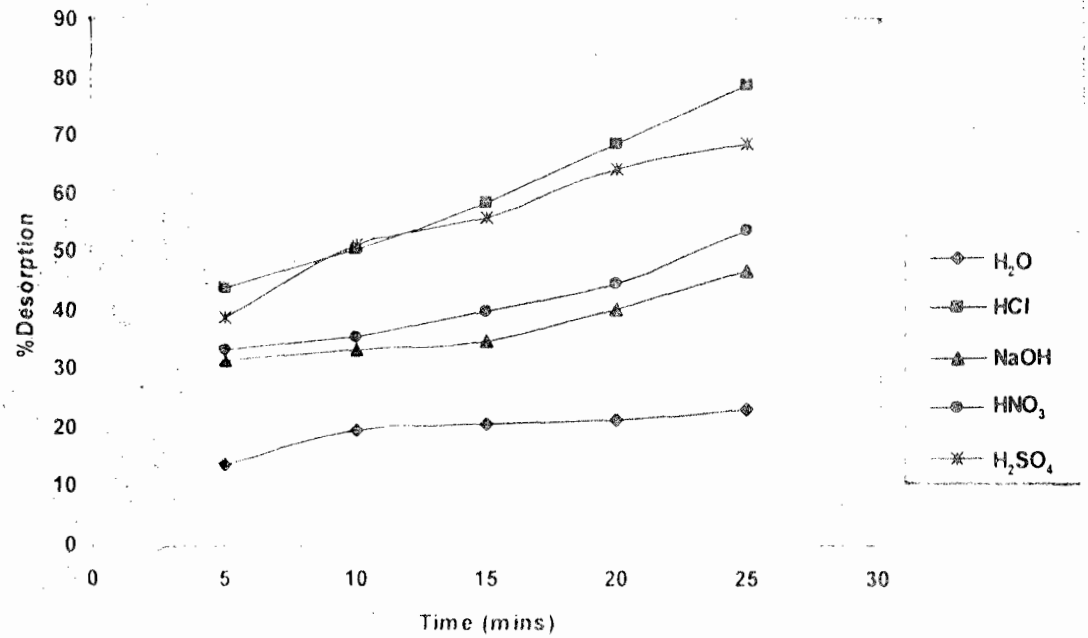

Fig.1:Percentage of metal desorbed versus contact time for UOPF

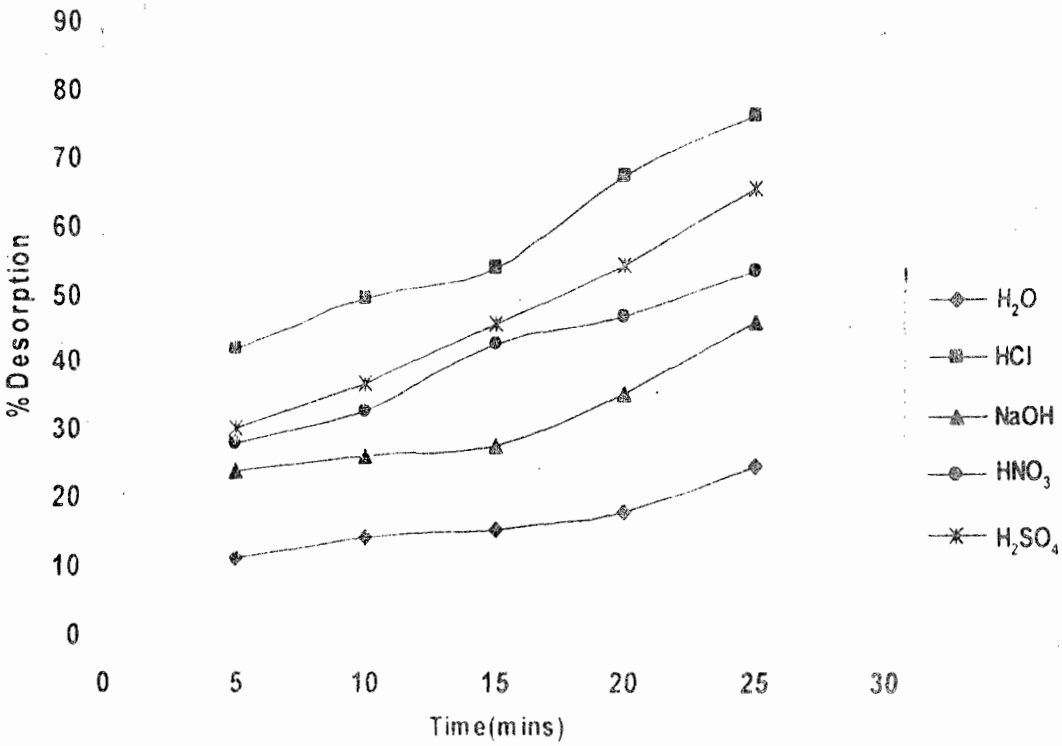

Fig.2: Percentage of metal desorbed versus contact time for 0.5MOPF

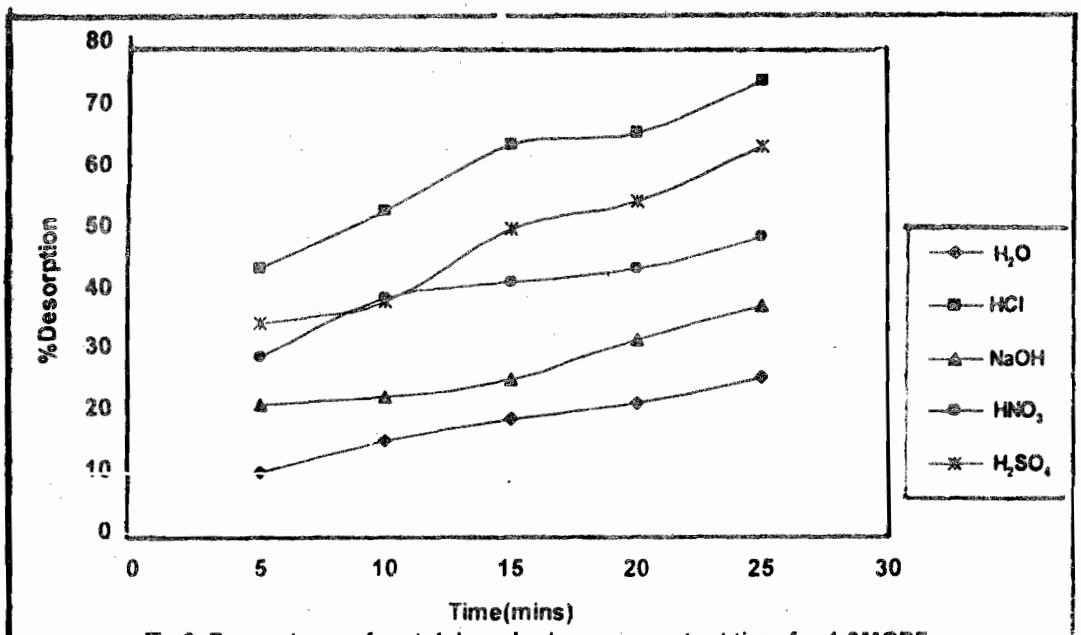

Fig.3: Percentage of metal desorbed versus contact time for 1.0MOPF

Thus it can be said that the desorption efficiency for the three adsorbents followed the trend; HCl > H_2SO_4 > NaOH > HNO_3 > H_2O. Furthermore, a decrease in desorption efficiency as chemical modification of the adsorbent increased was observed for three eluents; 0.1M NaOH, 0.1M H_2SO_4 and 0.1M HCl. This decrease in efficiency may be due to the nature of adsorbent-metal bond which makes the Cd(II) ion to be desorbed less for the chemically modified adsorbents. This property could be related to the strength of bond formed between the Cd(II) ion and the functional groups on the adsorbents. The property was also observed in the desorption of Cd(II) ions using HCl solution (Horsfall and Abia, 2003).

Comparatively, the acidic eluents (HCl, HNO_3 and H_2SO_4) had the highest percentage removal efficiency for all the three adsorbents. This may be due to the influence of pH of these solutions on the desorption mechanism. These acidic solutions tend to protonate the functional groups on the adsorbent surface. These groups are the carbonyl, hydroxyl and thiol groups. This is possible because at low pH, the proton concentration on the adsorbent surface is high. When these groups are protonated, there is high electro static repulsion of the metal ion (Cd^{2+}) thereby leading to its desorption from the adsorbent surface. Thus making the acids to be the most efficient eluents, in the system especially HCl. This trend was also observed in the desorption of cadmium from algae using HCl solution. (Fraile *et al*, 2005).

Desorption of cadmium (II) ion using a basic solution (0.1M NaOH) gave removal efficiencies of 46.74%, 46.59% and 37.0% for UOPF, 0.5MOPF and 1.0MOPF respectively. This low extent of desorption may be due to the contribution of the pH of the solution. For at alkaline pH the functional groups on the adsorbent (COOH, OH and SH) become deprotonated. This thereby causes these groups to bind strongly to the cadmium ion as there is a charge reversal on the adsorbent surface at this pH. Thus the desorbing solution cannot effectively remove the cadmium ion from the adsorbents surface. This low efficiency was also observed in the desorption of Pb^{2+} and Cu^{2+} from Nipa palm (Wankasi *et al*, 2005).

Furthermore, from Figures 1 – 3, it is observed that the least desorbing solution for removal of Cd^{2+} from the three adsorbents was hot deionized water. The desorption efficiencies for this solution were 23.10%, 24.89% and 25.39% for UOPF, 0.5MOPF and 1.0MOPF adsorbents respectively. This low efficiency of this solution is due to the influence of the pH of the hot deionized water, which was at 7.1. The fractional amount of the cadmium ion desorbed may be due to the increased temperature of the solution which aids metal desorption. The temperature of the hot deionized water was 60^0C. It has been reported that high temperature favours metal ion desorption (Fraile *et al*, 2005).

KINETIC MODELING OF Cd^{2+} DESORPTION

In order to investigate the mechanism of Cd^{2+} desorption from the three adsorbents using the five different eluents two kinetic models were used. Desorption kinetic modeling describes the rate of desorption of an adsorbate and evidently this controls the residence time of an adsorbate at the solid-liquid interface. The fitting parameter used to determine which of the models better describes the mechanism of desorption of Cd^{2+} on the different adsorbents was the coefficient of determination, r^2 (Ho, 2006).

The Elovich kinetic equation (Chien and Clayton, 1989; Sparks, 1986) and the pseudo-first order desorption equation (Chu and Hasim, 2001) were used to model the desorption kinetics of Cd^{2+} from the three adsorbents (UOPF, 0.5MOPF and 1.0MOPF) using the five eluents.

ELOVICH DESORPTION KINETIC MODEL

The Elovich kinetic equation used for the modeling of desorption of Cd^{2+} was the linearised form of the equation (Eq. 7). Figure 4 presents the Elovich desorption plot for UOPF, while Figures 5 and 6 are the Elovich desorption plots for 0.5MOPF and 1.0MOPF adsorbents respectively. The Elovich desorption rate constant, β and the constant α computed from the plots of Figures 4-6 are presented in Tables 1, 2 and 3. From Tables 1, 2 and 3 it can be seen that the desorption rate constant, β values were highest for 0.1M HCl eluent in all the three adsorbents.

This indicates that the 0.1M HCl eluent was the most efficient desorbing solution for Cd(II) ion. Furthermore, it can also be deduced that the Elovich desorption rate constant of all the eluents, β decreased with increase in chemical modification of the adsorbent. This may be due to the nature of chemical interaction between the functional groups on the adsorbent surface and the cadmium (II) ion. This makes the desorbing solutions to be less capable of desorbing the metal ion from the adsorbent surface.

The constant, α in the Elovich equation accounts for the rate of metal ion resistance to desorption. This is the initial

adsorption rate. For UOPF adsorbent hot deionized water had the highest value of 3.26×10^{-1} mg g^{-1} min^{-1}, while for 0.5MOPF and 1.0MOPF adsorbents the highest values were recorded for hot deionized water and 0.1M NaOH respectively. This indicates that for these adsorbents, the tendency of the metal ion to remain on the adsorbent surface tends to be greater than ease towards desorption.

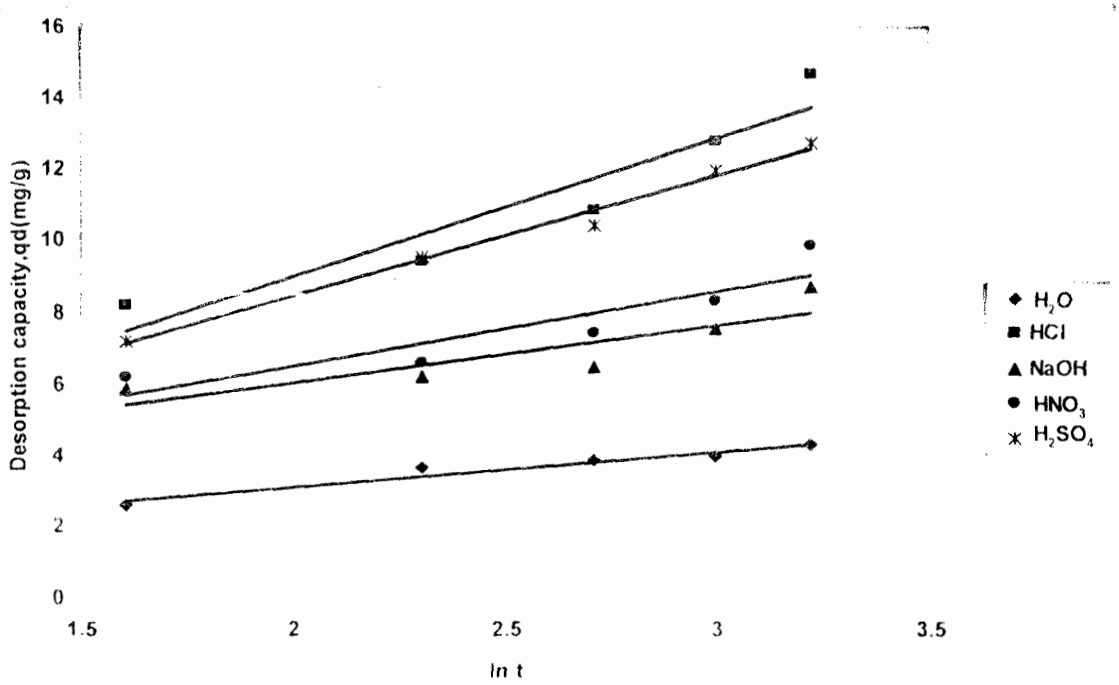

Fig.4: Elovich desorption kinetic model for Cd(II) ion on UOPF

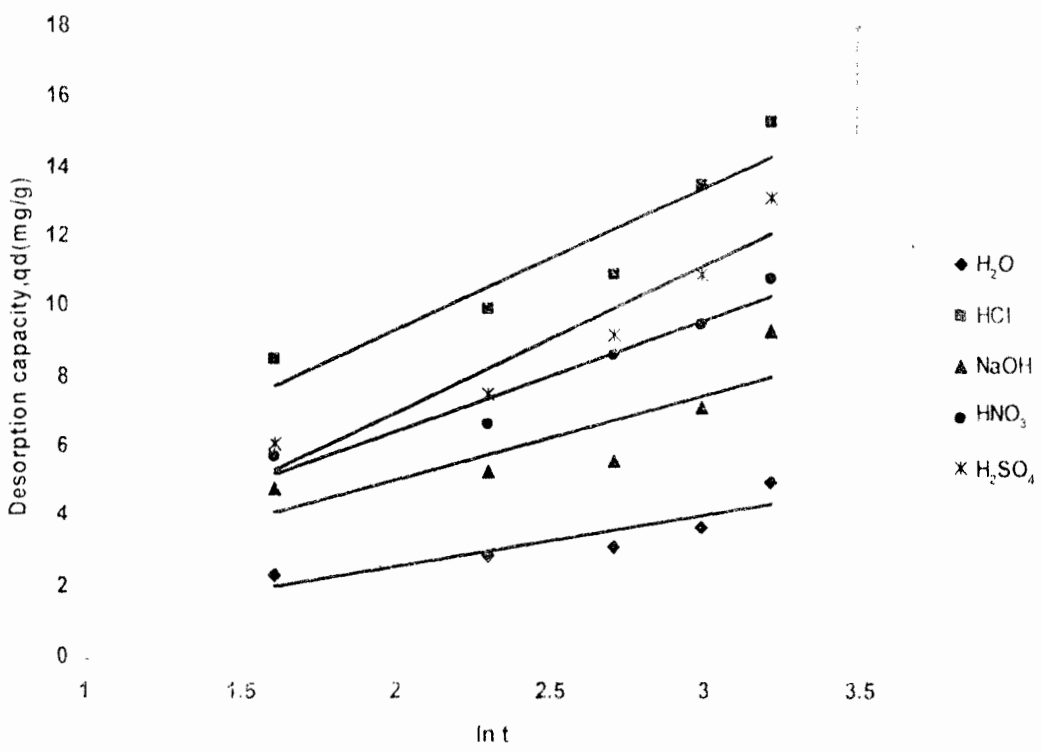

Fig.5: Elovich desorption kinetic model for Cd(II) ion on O.5MOPF

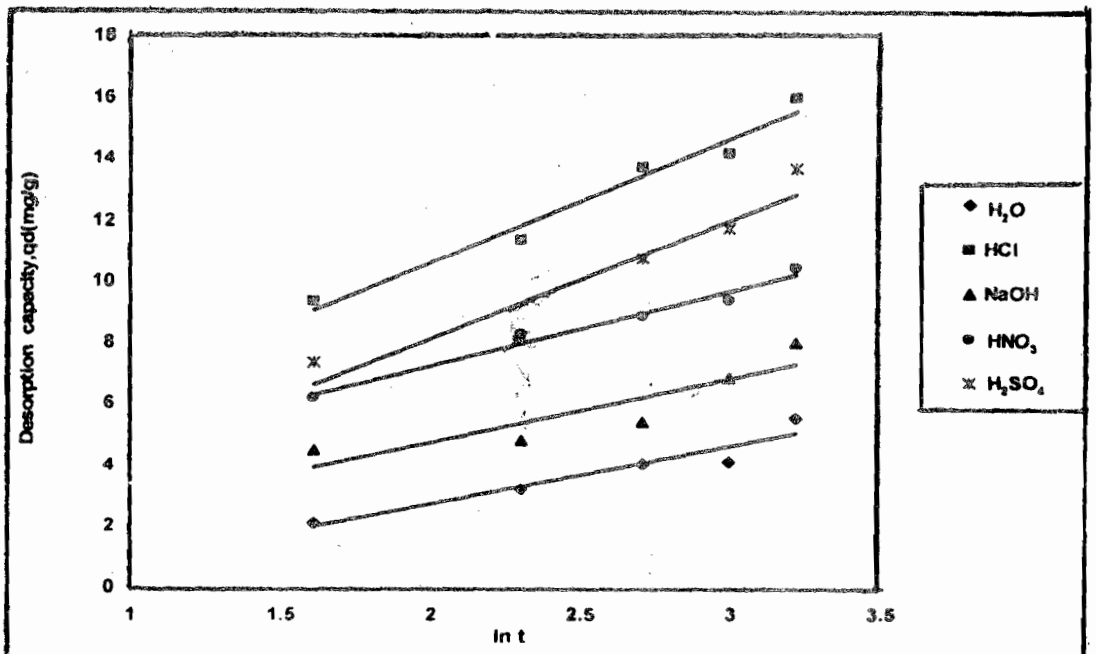

Fig.6: Elovich desorption kinetic model for Cd(II) ion for 1.0MOPF

Table1: Elovich Desorption Rate Constants of Cd^{2+} from UOPF Adsorbent

Desorption Reagent	$\alpha(mg.g^{-1}.min^{-1})$	$\beta(mg.g^{-1}.min^{-1})$	r^2
Hot deionized H_2O	3.26×10^{-1}	0.198	0.9450
0.1M HCl	2.11×10^{-3}	0.657	0.8974
0.1M NaOH	6.47×10^{-3}	0.230	0.7573
0.1M HNO_3	3.63×10^{-3}	0.481	0.8100
0.1M H_2SO_4	1.03×10^{-3}	0.494	0.9857

Table 2: Elovich Desorption Rate Constants of Cd^{2+} from 0.5MOPF Adsorbent

Desorption Reagent	$\alpha(mg.g^{-1}.min^{-1})$	$\beta(mg.g^{-1}.min^{-1})$	r^2
Hot deionized H_2O	9.39×10^{-2}	0.149	0.7940
0.1M HCl	2.21×10^{-3}	0.443	0.8773
0.1M NaOH	2.58×10^{-1}	0.212	0.7073
0.1M HNO_3	2.27×10^{-2}	0.316	0.9394
0.1M H_2SO_4	1.12×10^{-2}	0.338	0.9077

Table 3: Elovich Desorption Rate Constants of Cd^{2+} from 1.0MOPF Adsorbent

Desorption Reagent	$\alpha(mg.g^{-1}.min^{-1})$	$\beta(mg.g^{-1}.min^{-1})$	r^2
Hot deionized H_2O	2.48×10^{-1}	0.127	0.9192
0.1M HCl	7.62×10^{-6}	0.398	0.9703
0.1M NaOH	1.49×10^{-1}	0.203	0.7938
0.1M HNO_3	1.36×10^{-3}	0.306	0.9746
0.1M H_2SO_4	6.14×10^{-2}	0.320	0.9018

Pseudo-First Order Desorption Model

The second equation for modeling of desorption kinetics for cadmium (II) ion was the pseudo-first order equation (eq.10). The plots of the pseudo-first order equation for UOPF, 0.5MOPF and 1.0MOPF are presented in Figures 7, 8 and 9. The kinetic parameters from the pseudo-first order plots; the release constant, K_{des} and the desorbable fraction, θ are presented in Tables 4, 5 and 6 for UOPF, 0.5MOPF and 1.0MOPF respectively. From the Tables it can be seen that hot deionized water had the least desorbable fraction of the initial metal loading, θ, with values of 0.135, 0.070 and 0.050 for UOPF, 0.5MOPF and 1.0MOPF adsorbents respectively. This corroborates the view that the hot deionized water was the least efficient desorbent for removal of Cd^{2+} ion.

One other property that relates to an adsorbed molecule which is related to desorption kinetics is the surface residence time, τ. This is the average time that a molecule will spend on the surface under a given set of conditions before it desorbs into the aqueous phase. The residence time is very essential because the higher the residence time, the longer the contact between the desorption reagent and the metal loaded adsorbent. Hence, residence time must be relatively small in order to protect the deterioration of the adsorbent and enhance its recyclable life time. (Wankasi *et al*, 2005).

From the pseudo-first order desorption equation, the average surface residence time prior to the desorption process occurring may be given as:

$$\tau = \frac{1}{K_{des}} \quad - \quad - \quad 11$$

The surface residence times, for the three adsorbents using the five eluents is presented in Tables 4, 5 and 6. From the Tables it was observed that 0.1M HCl eluent had the least surface residence time for the three adsorbents; 31.4 seconds,

33.8 seconds and 30.72 seconds for UOPF 0.5MOPF and 1.0MOPF respectively whereas the surface residence time for the hot deionized water were 400.4 seconds, 349 seconds and 306.6 seconds for UOPF, 0.5MOPF and 1.0MOPF respectively. It can be deduced that the shorter the surface residence time, τ the more efficient is the desorbing solution.

The relatively short residence time for the 0.1M HCl eluent shows that this eluent was the most efficient in the desorption of Cd^{2+} ions from the three adsorbents. This short residence time indicates that the HCl eluent has a potential of preserving the adsorbent for further use.

The analysis of the kinetics models using the fitting parameter, the coefficient of determination, r^2 was used to determine which of these two models better describes the mechanism of desorption. The r^2 values for the elovich desorption and the pseudo-first order desorption equations are presented in Tables 1-6. Examination of the two desorption models using the r^2 values shows that the Pseudo-first order equation had the highest r^2 values for the three adsorbents.

Thus the pseudo-first order kinetic model can be said to describe the kinetics of desorption of cadmium (II) ion from the three adsorbents better. Hence the mechanism of desorption of Cd^{2+} follows a pseudo-first order kinetic model.

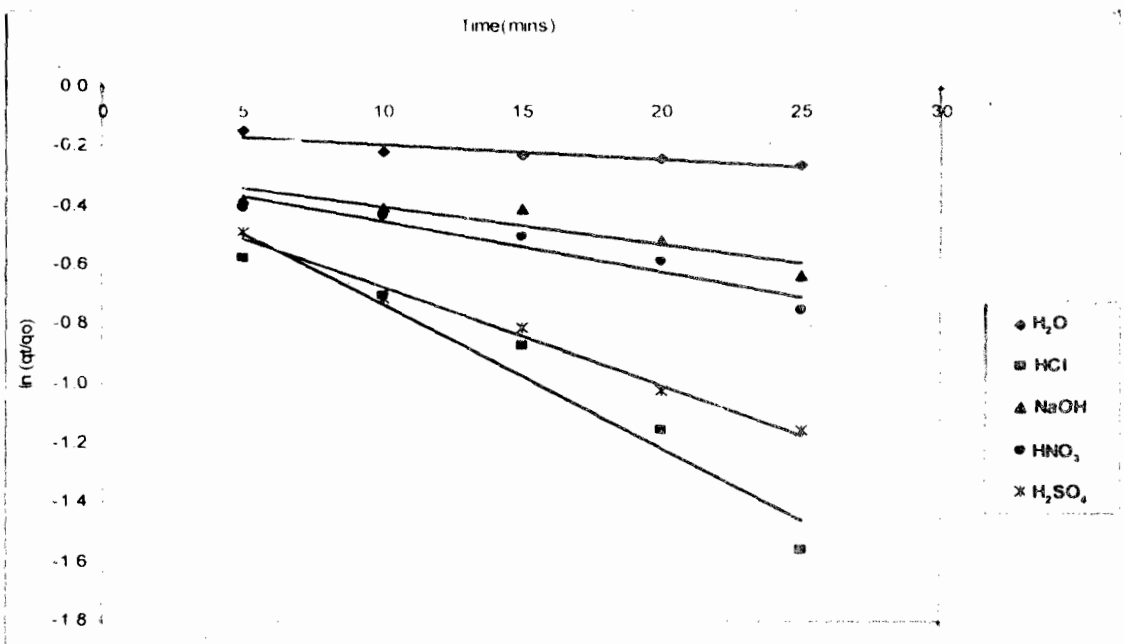

Fig 7 Pseudo first order kinetics for Cd(II) ion desorption for UOPF

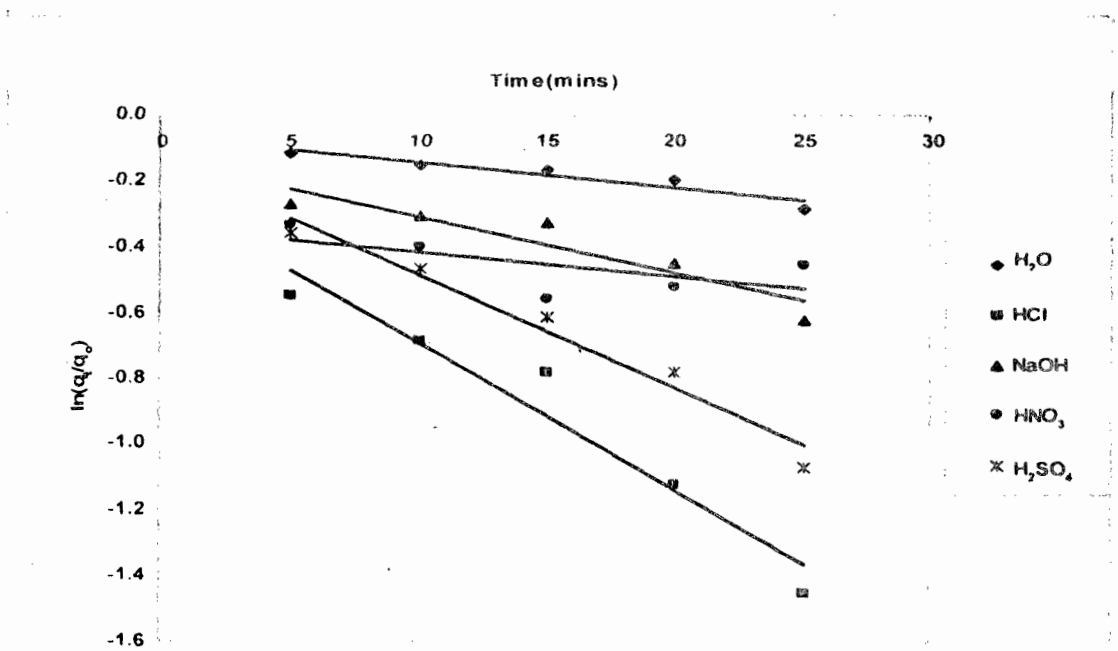

Fig.8: Pseudo-first order kinetics for Cd(II) ion desorption for 0.5MOPF

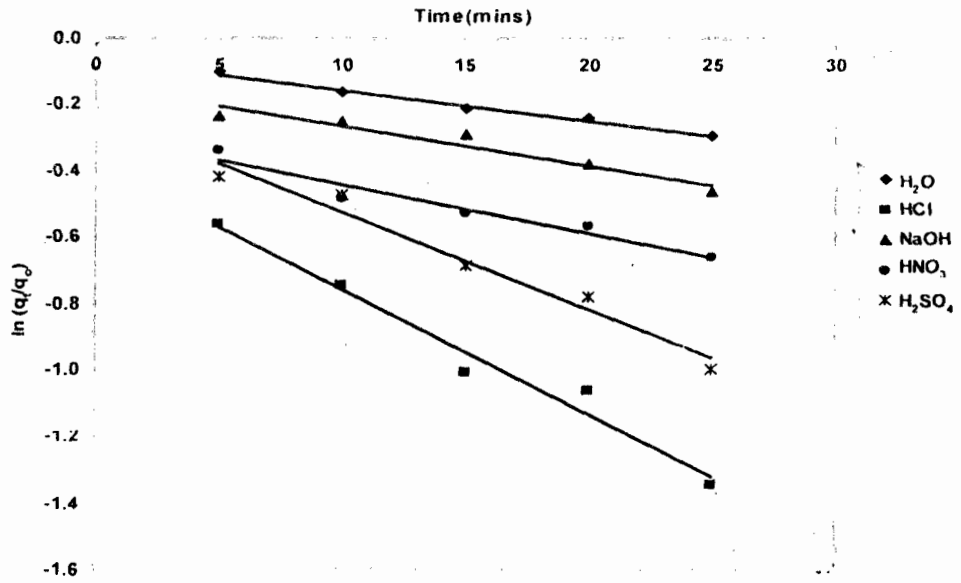

Fig.9: Pseudo-first order kinetics for desorption of Cd(II) ion from 1.0MOPF

Table 4: Pseudo-first Order desorption rate constants of Cd^{2+} from UOPF adsorbent

Desorption Reagent	K_{des} (min^{-1})	θ	ζ (Secs)	r^2
Hot deionized H_2O	2.49 X 10^{-3}	0.135	400.4	0.8344
0.1M HCl	3.18 X 10^{-2}	0.420	31.4	0.9487
0.1M NaOH	9.01 X 10^{-3}	0.200	110.9	0.8606
0.1M HNO_3	1.22 X 10^{-2}	0.247	81.7	0.9248
0.1M H_2SO_4	2.68 X 10^{-2}	0.294	37.2	0.9875

Table 5: Pseudo-first order desorption rate constants of Cd^{2+} from 0.5MOPF adsorbent

Desorption Reagent	K_{des} (min^{-1})	θ	ζ (Secs)	r^2
Hot deionized H_2O	2.85 X 10^{-3}	0.070	349	0.9026
0.1M HCl	3.95 X 10^{-2}	0.318	33.8	0.9407
0.1M NaOH	9.39 X 10^{-3}	0.132	119	0.8639
0.1M HNO_3	1.07 X 10^{-3}	0.270	164.6	0.4195
0.1M H_2SO_4	2.71 X 10^{-2}	0.228	58.4	0.9654

Table 6: Pseudo-first order desorption rate constants of Cd^{2+} from 1.0MOPF adsorbent

Desorption Reagent	K_{des} (min^{-1})	θ	ζ (Secs)	r^2
Hot deionized H_2O	3.26 X 10^{-3}	0.050	306.5	0.9914
0.1M HCl	3.25 X 10^{-2}	0.315	30.72	0.9735
0.1M NaOH	5.87 X 10^{-3}	0.134	170	0.9293
0.1M HNO_3	1.06 X 10^{-2}	0.204	93.7	0.9437
0.1M H_2SO_4	1.84 X 10^{-2}	0.220	54.2	0.9688

CONCLUSION

The kinetics of desorption of Cd (II) ion from three adsorbents (UOPF, 0.5MOPF and 1.0MOPF) previously used for adsorption of the metal was carried out using five different acidic, basic and neutral solutions.

The percentage desorption efficiency of the Cd^{2+} from the three adsorbents followed the trend; Hot deionized H_2O < 0.1M NaOH < 0.1M HNO_3 < 0.1M H_2SO_4 < 0.1M HCl.

Kinetic modeling analysis of desorption data using the Elovich equation and the pseudo-first order equation using the coefficient of determination, r^2 as the fitting parameter indicates that the pseudo-first order equation was the better model for description of desorption kinetics of Cd^{2+} from the 3 adsorbents.

This study confirms the notion that acids are the best desorbing media for heavy metals from adsorbent surfaces, with HCl solution giving the highest removal efficiency.

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