



Research article

Investigation of Taguchi optimization, equilibrium isotherms, and kinetic modeling for cadmium adsorption onto deposited silt

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ABSTRACT

The feasibility of deposited silt as an adsorbent to eliminate Cadmium (Cd) from aqueous solution is assessed in this study. The optimum adsorption condition was determined with the help of the Taguchi experimental design. The treatment process of the deposited silt is controlled by various parameters like pH of the solution; a dose of deposited silt; initial Cd metal concentration, and contact time are optimized in batch mode. It also recognizes the contribution of each well-regulated factor. The outcomes of experiments show that the major contribution of the controllable factors for Cd removal is the pH of the solution > stirring time > dose of deposited silt > initial concentration of Cd metal ions. Analysis of Variance (ANOVA) was used to determine significant parameters which contribute to the adsorption process. Results indicate that cadmium removal is mostly influenced by pH 88.17 %, followed by contact time 5.86%, adsorbent dose, 2.41%, and initial metal ion concentration 0.60%. Cadmium adsorption data well fitted to the Langmuir isotherm model. The pseudo-second-order is the best model that explained cadmium adsorption kinetics.

1. Introduction

Water pollution is found to be a major global issue that right away needs methods for planning and enforcement of solutions [1]. Heavy metal pollution in surface as well as subsurface sources is one of the hazards to human life. Heavy metal sources are classified into two natural processes such as rock erosion-weather cycle and anthropogenic activities [2]. Energy generation by a thermal power plant is the major source of heavy metal contamination in the environment among all human activities [3]. Coal fly ash, the major by-product of thermal power plants, contributes to the most extensively studied contaminants. Fly ash particles are widely dissimilar, inhomogeneous, and have contrasting morphologies. The disposal of ash from thermal power generation and its potential environmental effects are global issues [4]. Every year millions of tons of hazardous coal ash waste, a by-product of coal combustion for power generation, are haphazardly dumped into unlined, untreated lagoons. Carcinogen-filled storage, this waste sinks into groundwater and contaminates local water bodies [5]. The condensation of metal and metalloid vapors on the core refractory materials is a process that appears

to be common to all ashes during their creation. Air surfs from the combustion chamber to the flue gas, resulting in locally higher concentrations of certain trace elements on the surface of the ash particles, resulting in a generally higher concentration affected by the particle size [6]. Whenever the natural ecosystem is exposed to harmful heavy metals, the accumulation of metal ions in human bodies can occur either through direct ingestion or through food chains, which is why heavy metals should not reach the natural environment [7]. Conventional techniques such as chemical precipitation, coagulation, ion exchange, solvent extraction and filtration, evaporation, and membrane techniques have been used to eliminate hazardous heavy metals from the water system [8]. Heavy metal adsorption on conventional adsorbents such as activated carbon has been extensively used as an efficient adsorbent in many applications and activated carbon produced by carbonizing organic matter. Although, the high cost of the activation process limits its utilization in wastewater treatment applications [9]. The demand for low-cost adsorbents with metal binding capabilities has increased in recent years. Locally available materials can be used as low-cost adsorbents in large quantities [10]. Due to its physical and chemical properties

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as a significant specific area, cation exchange capacity and adsorptive affinity for organic and inorganic ions, natural zeolite, natural bentonite, and natural clay can be classified as effective low-cost adsorbents [11]. Calcined phosphate used for removal of Pb^{2+} , Cu^{2+} , and Zn^{2+} [12], Montmorillonite and vermiculite as solid phases applies for the exclusion of As, Ba, Cu, Cd, Co, Cr, Mn, Ni, Pb, Sr, V, and Zn [13], Polycyclic aromatic hydrocarbons (PAHs); naphthalene and pyrene and one cyclic aromatic hydrocarbon adsorbed using clay and sandy soil [14]. Besides, carbon dioxide adsorption on raw Chorfa silt material studied by Fatima Ouadjenia [15]. Agriculture by-product i.e., walnut shell and grain rice are implemented to exclude Zinc and Nickel from industrial wastewater [16]. The modification of a natural adsorbent (pine bark) with Fenton's reagent (hydrogen peroxide and ferrous ions) for cadmium removal was intended to benefit of the Fenton destroy of organic components in barks [17]. Maghnite used for adsorption of Cu(II) in aqueous solution [18]. Green coconut shells applied as an adsorbent for the removal of toxic metal ions such as Cu^{2+} , Pb^{2+} , Cd^{2+} , Zn^{2+} , Ni^{2+} [19], Sweet Potato Skin is used for biosorption of Cadmium [20], Synthesized magnetic graphene oxide is applied for removal of toxic heavy metal ions such as Pb^{+2} , Cr^{+3} , Cu^{+2} , Zn^{+2} and Ni^{+2} [21], Nanobentonite integrated Nanocellulose/Chitosan aerogel (NCNB) is used for the optimization of chromium, cobalt and copper adsorption [22]. Clay soil mixed with different admixtures (cement, gypsum, lime, and bentonite) implemented in the removal of Cadmium [23]. Chorfa silt material (Mascara, Algeria) used for removal of Cu(II), Cd(II) removal is about 55 % and Cr(III) [24]. Untreated coffee grounds effectively used for eliminating cadmium with kinetic adsorption on coffee grounds have been well fitted by kinetic model of second order rather than first order model [25]. The two Tunisian clays from Jebel Chakir and Jebel Tejra are used for the adsorption of cadmium and chromium along with their effect on the Zeta potential of clay [26]. Experimental optimization was usually done by monitoring the influence of one factor at a time on the experimental response. Since only one parameter is modified, other parameters are kept at a constant rate. This optimization strategy is referred to as one-variable-at-a-time optimization. Its main limitation is that it does not provide an interactive effect between the variables studied. As significant as that, this technique does not represent the actual impact of the parameter on the response [18]. Another disadvantage of one-variable-at-a-time optimization is the increase in the number of experiments needed for research, which contributes to an increase in time and cost as well as an increase in the use of reagents and resources [27]. To solve this problem, multivariate statistic approaches are used to optimize analytical processes. Among the most important multivariate techniques used in analytical optimization is the use of the Taguchi Method implemented for Cd adsorption. Taguchi designs use orthogonal arrays, which estimate the effects of factors on the response mean and variation [28, 29]. Orthogonal arrays allow you to investigate each effect independently from the others and may reduce the time and cost associated with the experiment when fractionated designs are used. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments & desired output in form of optimum experimental conditions, serve as objective functions for optimization, helps in data analysis, and prediction of optimum results [30, 31]. Taguchi design methods are used by many researchers such as removal of heavy metals from wastewater by modified mesoporous carbon [32], Spent coffee for adsorption of Cd(II) [33], Natural zeolite used in adsorption of Phosphorus [34], Waste coffee residues are used to remove heavy metals (Cu^{2+} , Pb^{2+} , and Zn^{2+}) from aqueous solutions [35].

The goal of this study is to use the experimental design of Taguchi to investigate significant factors that would have a significant impact on the adsorption efficiency of deposited silt as an adsorbent in the removal of Cd metal ions from aqueous solutions. The objective is to obtain optimum operating conditions for the effective use of the deposited silt for industrial as well as large-scale applications. However, the validity of both Langmuir and Freundlich adsorption isotherms also have been verified.

2. Materials and methods

2.1. Preparation of deposited silt as an adsorbent

The deposited silt used in this experiment was collected from the Godavari River bank near Kopargaon town, Dist. Ahmednagar (MS, India). The deposited silt is granular in form, brown in colour, and particle size varies between sand and clay from 0.05 to 0.002 mm, with a specific mineral composition of quartz and feldspar. To remove any undesirable matter present in it, deposited silt is washed, then dried in sunlight initially for 24 h, followed by drying in hot air oven at 105 °C for 2 h. The cadmium standard stock solution was prepared using the APHA procedure.

2.2. Characterization of adsorbent

The physico-chemical composition of deposited silt is given in Table 1. Ever since of its physical characteristics, it confirms a high percentage with sand and helps to attain equilibrium conditions faster than one with clayey soils. This is because of the better permeability of the sandy soil [14].

XRD, SEM and EDS analysis are carried out to identify the mineral composition and morphological features of adsorbent. Mineralogical composition is determined by the analysis of X-ray diffractograms (XRD), which involved the identification and semi-quantification of the representative peaks of the minerals in the sample. X-ray diffraction study is carried out on Philips, Holland X-ray diffractometer. The surface morphologies of the adsorbent are inspected by a Scanning Electron microscopy (SEM) and Energy Dispersive Spectroscopy (EDS). The electron microphotographs are recorded in the JEOL-JSM-6360A operating at 20KV. The deposited silt sample is analysed under SEM at different magnification. To identify the functional group responsible for the adsorption in the Deposited silt, Fourier transform infrared spectroscopy (FTIR) analysis is carried out, shown in Figure 3.

2.3. Experimental methods

Taguchi Method involves the identification of proper control factors to obtain the optimum results of the process. Orthogonal Arrays (OA) are used to conduct a set of experiments. Taguchi Orthogonal Array (OA) design is a type of general fractional factorial design. It is a highly fractional orthogonal design that is based on a design matrix proposed by Dr. Genichi Taguchi and

Table 1. Physio-chemical property of deposited silt.

Analysis	Values	Analysis	Values
Specific Gravity	2.475	SiO ₂	34.36 %
Bulk Density	1.968 gm/cm ³	Al ₂ O ₃	19.84 %
Loss of Ignition	4.94 %	Fe ₂ O ₃	5.26 %
Sand	41.93 %	MgO	0.56 %
Clay	38.70 %	SO ₄	0.0018 %
Silt	19.35 %	pH	7.82 at 25 °C
pH zpc	4.90 at 25 °C	Cation Exchange capacity	32.53 meq/100 gm

Table 2. Controllable factors and associated levels.

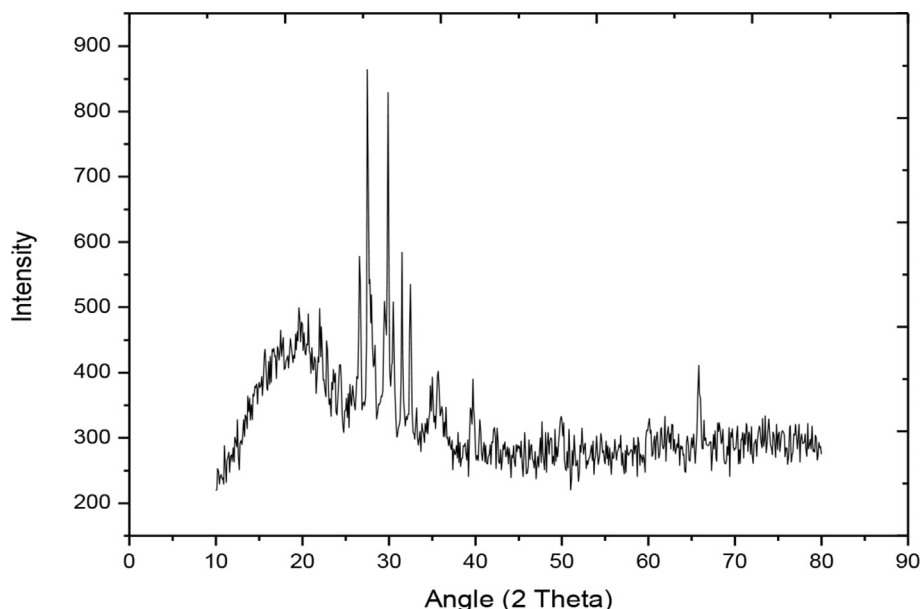
Factor	Description	Levels				
		L ₁	L ₂	L ₃	L ₄	L ₅
A	pH	4	5	6	7	8
B	Initial Cd Conc.(mg/L)	1	2	3	4	5
C	Adsorbent Dose (g/L)	20	40	60	80	100
D	Stirring time (minutes)	30	60	90	120	150

Table 3. Removal of Cd and S/N ratios.

Runs	A	B (mg/L)	C (g/L)	D (minutes)	Removal (%)			Average Removal (%)	S/N ratio
					R1	R2	R3		
1	4	1	20	30	93.7	93.8	93.9	93.8	39.44
2	4	2	40	60	88.7	89.8	89.9	89.5	39.04
3	4	3	60	90	87.0	87.6	88.4	87.7	38.86
4	4	4	80	120	92.9	93.1	94.6	93.5	39.42
5	4	5	100	150	90.7	91.2	92.1	91.3	39.2
6	5	1	40	90	93.9	94.4	94.4	94.2	39.48
7	5	2	60	120	97.6	98.9	97.2	97.9	39.81
8	5	3	80	150	95.3	95.9	96.4	95.8	39.62
9	5	4	100	30	97.4	97.5	97.7	97.5	39.78
10	5	5	20	60	94.6	94.7	94.5	94.6	39.51
11	6	1	60	150	98.3	98.8	98.3	98.5	39.87
12	6	2	80	30	98.6	98.3	98.7	98.5	39.87
13	6	3	100	60	96.7	96.4	96.7	96.6	39.7
14	6	4	20	90	96.5	96.7	96.4	96.6	39.7
15	6	5	40	120	98.9	99.4	99.1	99.1	39.92
16	7	1	80	60	96.3	96.8	97.2	96.8	39.71
17	7	2	100	90	90.2	90.5	90.4	90.4	39.13
18	7	3	20	120	96.1	96.3	96.2	96.2	39.67
19	7	4	40	150	91.4	91.7	91.9	91.7	39.25
20	7	5	60	30	96.7	97.3	96.9	97.0	39.74
21	8	1	100	120	64.4	64.8	64.6	64.6	36.2
22	8	2	20	150	77.7	77.8	78.2	77.9	37.83
23	8	3	40	30	68.4	68.9	68.7	68.7	36.74
24	8	4	60	60	80.5	80.7	80.3	80.5	38.11
25	8	5	80	90	61.9	62.4	62.2	62.1	35.86

allows you to consider a select subset of combinations of multiple factors at multiple levels. Taguchi Orthogonal arrays are balanced to ensure that all levels of all factors are considered equally [36, 37]. The controllable factors considered in this study are the pH, Initial Cd concentration, Adsorbent (deposited silt) dose, and stirring time. They are denoted by A, B, C, and D respectively. Each controllable factor had five testing conditions (represented by levels L1, L2, L3, L4, and L5 respectively, as usually performed in the Taguchi approach) as illustrated in Table 2. Particularly, they are 4, 5, 6, 7 and 8 for A; 1, 2, 3, 4 and 5 mg/L for B; 20, 40, 60, 80 and

100 g/L for C; 30, 60, 90, 120 and 150 min for D. For the arrangement of Table 2, a full factorial experimental design of four factors with five levels each would require a total of 5^4 (625) experiments. The orthogonal array could significantly reduce the number of experiments. Several differently designed arrays such as L16 (16 experiments) and L25 (25 experiments) are available. In this study, the orthogonal array of L25 is chosen because of the complexity and resources, as shown in Table 3. Hence, the number of experiments is reduced from 625 to 25, a great reduction in time and cost.

**Figure 1.** XRD of deposited silt.

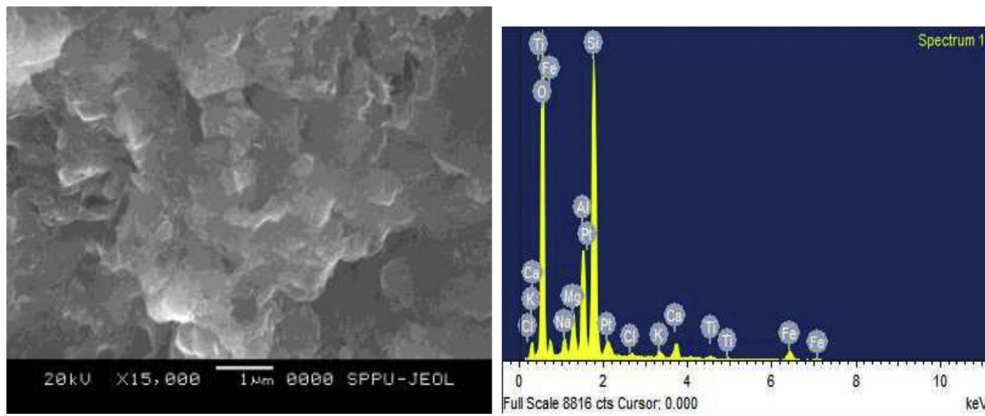


Figure 2. SEM and EDS images of deposited silt.

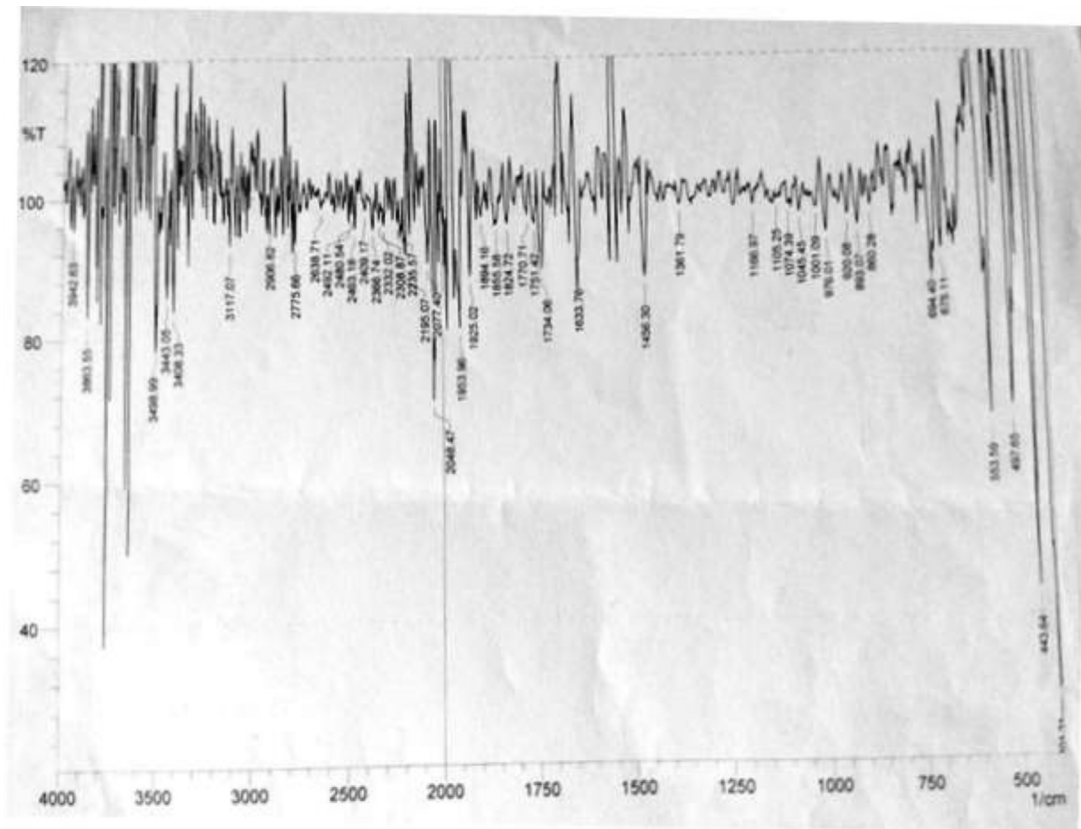


Figure 3. Infrared Spectra of deposited silt.

In the Taguchi method, the signal-to-noise ratio is a logarithmic variable used to optimize the design of the process or product to reduce the variability. The signal-to-noise ratio can also be understood as an

Table 4. Response table for signal to noise ratios for % cadmium removal.

Level	pH	Initial Metal Conc.	Adsorbent Dose	Stirring Time
1	39.19	38.94	39.23	39.11
2	39.64	39.13	38.88	39.21
3	39.81	38.92	39.28	38.60
4	39.50	39.25	38.90	39.00
5	36.95	38.85	38.80	39.16
Delta	2.86	0.40	0.47	0.61
Rank	1	4	3	2

inverse of variance and maximization of signal-to-noise ratio enabling for reduction of process variation against unintended changes in the adjacent environment (also called uncontrollable factor or factor of noise) [28]. The obtained experimental data are processed with the “Larger is Better” (LB) quality characteristic (as given by Eq. (1)) to determine the optimum conditions and identify the significance of individual parameters in Cd removal [38].

$$S / N_{LB} = -10 \log \left[\frac{1}{n} \sum_{i=1}^n \frac{1}{R_i^2} \right] \tag{1}$$

where “larger-the-better” is expressed by the subscript LB, n is the number of repetitions under the same experimental conditions and R_i expresses the measurement performance.

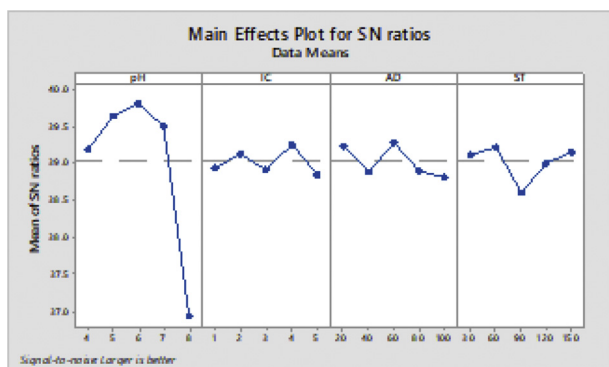


Figure 4. Response distribution of S/N ratios.

Table 5. Analysis of variance for transformed response of % removal data.

Variance Source	DOF	SS	MS	F-ratio	P-Value	% Contribution
pH	4	1327.31	331.828	62.66	0.000	88.17
IC	4	9.04	2.259	0.43	0.786	0.60
AD	4	36.64	9.161	1.73	0.236	2.43
ST	4	89.96	22.490	4.25	0.039	5.98
Error	8	42.37	5.296			2.81
Total	24	1505.32				100

Batch experiments are carried out in an orbital shaker (Remi made) with the adsorbent-adsorbate suspension in a 250-mL sealed conical flask at a defined 200 rpm. The initial solution pH is controlled using 1N NaOH and 1N HCl during the sorption process, without any further changes. The flask contains a 50 mL Cd solution. Every experiment has been repeated 3 times. The samples of metal solutions are filtered using Whatman No. 42 filter paper at the end of the specified contact time, and the filtrate is analysed with an atomic absorption spectrometer (Shimadzu, AAS-6880) for residual Cd concentration. The percentage removal of Cd metal ions is given by Eq. (2)

$$\text{Removal(\%)} = \left(\frac{C_0 - C_e}{C_0} \right) \times 100 \quad (2)$$

where C_0 and C_e are initial and final Cd (mg/L) concentrations respectively.

3. Results and discussion

3.1. Characterization of adsorbent

High percentage of sand strongly indicated in the presence of silica, alumina, which are essential components of quartz and feldspar, plays an important role in metal ion adsorption [34]. The cation exchange capacity (CEC) also indicates the potential for adsorption according to Gatima et al research [39]. A high CEC value (>25) is a good indicator that a soil has a high clay and organic matter content and can hold a lot of cations [26]. The pH_{zpc} value indicates that deposited silt that possesses certain acidic functional groups (phenol, carboxylic, carbonyl, etc.) that can play a significant role in the adsorption process [40]. Figure 1 displays the XRD peaks of a sample for deposited silt. Deposited silt consists of Silicon dioxide, Aluminium oxide, Iron (III)oxide, Iron (III)oxide-hydroxide and Iron (II)oxide by comparing the data with JCPDS [23, 41]. In addition iron oxide may help as an active adsorption material for metal ions [42]. Silt morphologies that comprise Oxygen, Sodium, Magnesium, Aluminium, Silica, Potassium, Calcium, Iron and Titanium as shown in Figure 2 [43]. Figure 3 shows FT-IR study of deposited silt was done to confirm presence of silica, iron and aluminium. The spectra displayed number of peaks, indicating the complex nature of material examined.

The strong bond observed at 3117.07 cm^{-1} indicated the stretching of many C-H i.e. aromatic groups which is responsible for adsorption property. At wave length 1734.06 cm^{-1} , C = O double bonding of aldehyde group is present. At wave length 1456.30 cm^{-1} , C=C double bond (aromatic) is present. The wave length 1633.76 cm^{-1} shows the primary and secondary amines and amides bonding of N-H, which is also functional group on the surface of adsorbent. At wave length 2906.82 cm^{-1} indicates C-H bond i.e. alkane group is present. The bands at 553.59 cm^{-1} , and 443.64 cm^{-1} are due to Fe-O bond stretching [44].

3.2. Taguchi optimization

Table 4 reveals the effects of the 25 experiments concerning the removal average. The removal average is the average of three repeated experiments which also reported the individual removal in the table. It determines the S/N ratio by Eq. (1). The results show that the Cd removal average ranged from 62.06 to 99.10 %, depending on the combination of the controllable factors. The related S/N ratio for each stage of each individually controllable factor is drawn from those removal averages in Figure 4, which explains the logic of the Taguchi method. Figure 4 show that the strongest variation in S/N ratio occurred with solution pH followed by stirring time, deposited silt dose, and initial concentration of Cd. In other words, the pH of the solution is the most influential controllable factor while the least significant one is the initial concentration of Cd.

The response table show the average of each response characteristic (S/N ratios) for each level of each factor. The table include ranks based on Delta statistics, which compare the relative magnitude of effects. From the response Table 4, it is observed that pH value has the greatest influence on the S/N ratio also stirring time has the next greatest influence followed by Adsorbent dose and Initial concentration Cd.

3.3. The main effect plot for S/N ratio

Figure 4 shows the main effect of S/N Ratio of % Cadmium removal. From Figure 4 the optimum level of parameters is obtained at a pH of 6, Initial concentration of 4 mg/L, and the adsorbent dose of 60 g/L with a Contact time of 60 min. From the analysis, it is also found that pH value is the most influencing parameter for Cadmium removal followed by stirring time, Adsorbent dose, and initial concentration.

3.4. Implementation of ANOVA

The ANOVA analysis is conducted to assess the contribution of each controllable factor to the process response, which is the efficiency of removal of Cd ions. The ANOVA assessment also enables a greater

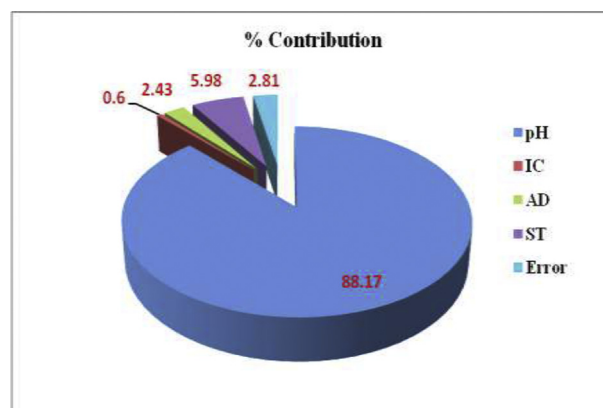


Figure 5. Contribution of various parameters for adsorption of Cd by deposited silt (calculated based on S/N data).

understanding of whether the findings obtained are acceptable and whether or not the experiments are undertaken within controlled conditions [34]. The results of the ANOVA are shown in Table 5. The errors are less than 50% contribution, which indicates that the experiments are performed under controlled conditions [31, 45]. Also, for the controllable variables, F values greater than 1 indicates that certain variables have variances greater than the variance of errors, suggesting that all controllable factors have major effects on the responses. It can be observed from the percentage contribution recorded in Table 5 that the pH (parameter A) is the most influential factor for the Cd adsorption by deposited silt. On the other hand, the initial metal concentration (parameter B) have the least impact which is correlated with other researchers observed results [38, 46, 47]. The contribution of each parameter for adsorption of Cd is shown graphically in Figure 5.

3.5. Adsorption isotherms

The relation between the amount of adsorbed substance per unit mass of adsorbent at constant temperature and its concentration in equilibrium is called isotherm adsorption. Adsorption isotherms usually provide crucial information in enhancing adsorbent utilization. Langmuir and Freundlich model are widely used to characterize isotherms of adsorption and provide important parameters to predict adsorption efficiency [33].

3.5.1. Langmuir isotherm

As a function of pressure up until the entire surface area is covered with a single layer of molecules and no further adsorption can occur, the Langmuir isotherm describes a gradually increasing surface occu-

Table 6. Langmuir and Freundlich isotherm parameters for Cd adsorption.

Langmuir Constants			Freundlich Constants		
Q_m	K_L	R^2	K_F	n	R^2
10.2564	0.0043	0.9993	0.0447	227.2727	0.0371

pancy [48]. The linear form of the Langmuir isotherm is expressed as below.

$$\frac{C_e}{Q_e} = \frac{1}{Q_m K_L} + \frac{C_e}{Q_m} \tag{3}$$

Q_e can be calculated experimentally by using the following equation

$$Q_e = \frac{(C_0 - C_e)V}{m} \tag{4}$$

Where, C_0 and C_e are initial and final liquid phase concentrations (mg/L), respectively. V is the volume of the solution (Litres), m is the mass of adsorbent (g) and Q_e (mg/g) is the amount of adsorbed metal at equilibrium. Q_m is a constant related to the area occupied by the single layer of the adsorbate which reflects the maximum adsorption capacity of Cd (mg/g) and K_L Langmuir constant is a direct measure of the adsorption intensity (L/mg). As shown in Figure 6, these constants are determined from the slope and intercept of the linear plot of C_e/Q_e vs. C_e . The deduced Q_m values from this plot were 10.2564, suggesting that deposited silt has a stronger adsorption potential for cadmium metal ions.

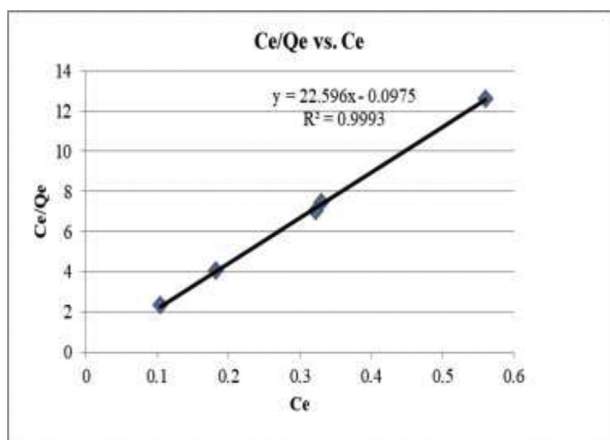


Figure 6. Langmuir Adsorption Isotherm for adsorption of Cd.

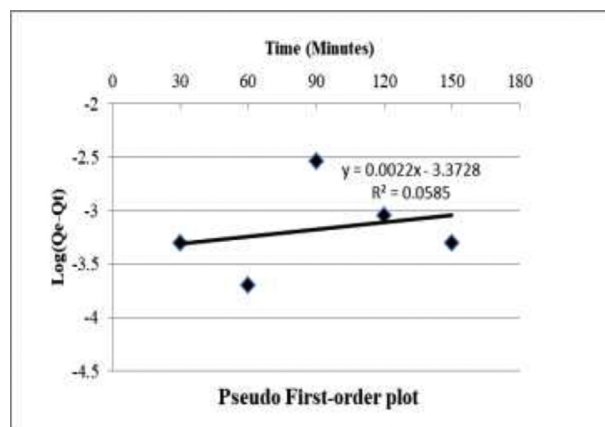


Figure 8. Pseudo First-order plots for the adsorption of Cd.

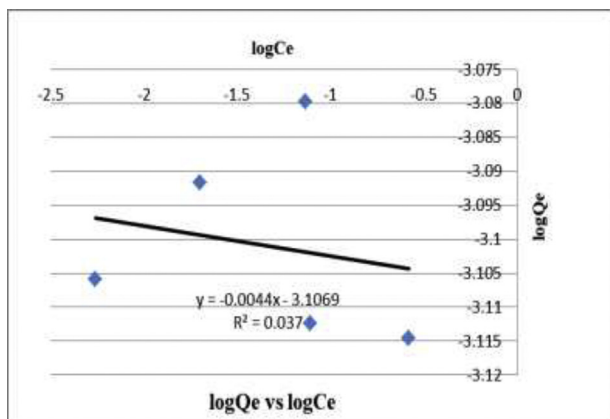


Figure 7. Freundlich Adsorption Isotherm for adsorption of Cd.

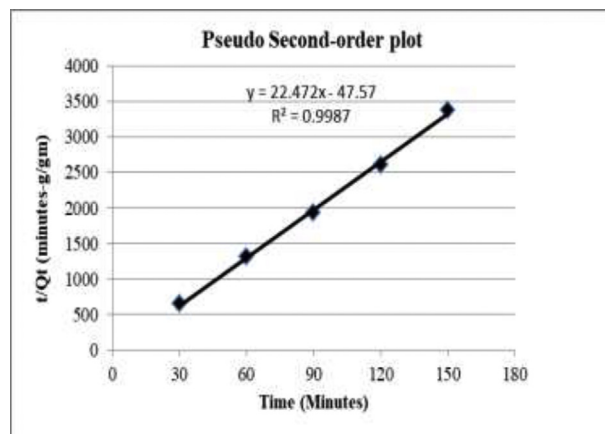


Figure 9. Pseudo Second-order plots for the adsorption of Cd.

Table 7. Pseudo first-order and pseudo second-order parameters for Cd adsorption.

Pseudo First-order constants				Pseudo Second-order constants				
$K_1 \text{ min}^{-1} (10^{-3})$	$Q_e \text{ (mg/g)}$ Expt.	$Q_e \text{ (mg/g)}$ Calc.	R^2	K_2	$Q_e \text{ (mg/g)}$ Expt.	$Q_e \text{ (mg/g)}$ Calc.	R^2	H
5.0666	0.0460	0.000423	0.0585	31.772	0.0460	0.0453	0.9978	0.0652

Table 8. Comparison of Q_m of Cd by various geological adsorbents.

Adsorbents	Adsorbent preparation	$Q_m \text{ (Mg/g)}$	Reference
Chorfa silt material	Washed and dried at 95 °C for 24 h	0.35	[24]
Celtek clay	washed and dried at 105 °C for 24 h	0.04	[52]
clay soil mixed with admixtures	air-dried for 24 h at 110 °C	4.409	[23]
Natural Jordanian (NJ) zeolite	the sample was washed, crushed and sieved	25.9	[53]
residual soil	air-dried, lightly ground and passes through 2 mm	2.7020	[54]
Kaolinite and Montmorillonite	Acid activated	11.4 & 33.2	[55]
Deposited silt	washed and dried at 105 °C for 24 h	10.2564	This Study

3.5.2. Freundlich isotherm

Adsorption isotherm experiments are conducted to determine the feasibility of an adsorption treatment. It is a balance test group that provides data on substance adsorbed per unit weight of adsorbent to the adsorbent amount remaining in the sample solution [49].

The Freundlich model assumes that on a disparate adsorbent surface, metal ion uptake occurs. This shows on the adsorbent surface the adsorption capacity or loading factor of the adsorbate. The Freundlich model is expressed as follows:

$$Q_e = K_f C^{1/n} \quad (5)$$

The logarithmic form of the equation is expressed as follows [49].

$$\log Q_e = \log K_f + \left(\frac{1}{n}\right) \log C_e \quad (6)$$

In this equation, K_f is the Freundlich constant denoting adsorption capacity (milligram per gram) and $1/n$ is the empirical constant indicating adsorption intensity (liter per milligram) and depends on the temperature and properties of adsorbate and adsorbent. As shown in Figure 7, constants are determined from the slope and intercept of the linear plot of $\log Q_e$ vs. $\log C_e$. The adsorption is chemical, physical, and linear for n being less than, greater than, and equal to one, respectively [50]. From the results illustrated in Table 6, the values of n of the deposited silt are greater than one, i.e. physical adsorption [33]. The calculated values of the constants in Langmuir and Freundlich equations and the regression correlation coefficients (R^2) are given in Table 6. Although the adsorbent Q_m obtained from the linear Langmuir model with higher R^2 values are all higher than that from the nonlinear Langmuir model, all of which are higher differences outside the observational data. It can therefore be presumed that, as for the deposited silt adsorption method for the removal of cadmium, the non-linear isothermal models may be even more powerful and feasible in modeling the isothermal adsorption data [51].

3.6. Adsorption kinetics

The pseudo-first-order kinetic model assumes that the rate of occupation of sorption sites is proportional to the number of unoccupied sites. The pseudo-first-order equation is expressed as follows

$$\text{Log}(Q_e - Q_t) = \text{Log}(Q_e) - \frac{K_1}{2.303} (t) \quad (7)$$

Where Q_e and Q_t (mg/g) are the adsorption capacities at equilibrium and t is time in min respectively. K_1 (min^{-1}) is the pseudo-first-order rate

constant for the kinetic model which can be calculated from the linear plot of $\log(Q_e - Q_t)$ vs. t , as shown in Figure 8.

The pseudo-second-order is based on the assumption that the rate-limiting step may be chemical sorption involving valence forces through sharing or exchange of electrons between heavy metal ions and adsorbent. The pseudo-second-order kinetic model also assumes that the sorption rate is proportional to the square of available unoccupied sites. The pseudo-second-order equation is expressed as follows

$$\frac{t}{Q_t} = \frac{1}{K_2 Q_e^2} + \frac{t}{Q_e} \quad (8)$$

Where, Q_e and Q_t (mg/g), is the adsorption capacities at equilibrium and time t in minute respectively. K_2 ($\text{g mg}^{-1} \text{min}^{-1}$) is the pseudo-second-order rate constant for the kinetic model which can be calculated from the linear plot of t/Q_t vs. t , as shown in Figure 9.

In Table 7, the calculated values of the constants in pseudo-first-order and pseudo-second-order equations, and the coefficients of regression correlation (R^2) are given.

A comparison of Cd adsorption by natural geological adsorbents as given in Table 8 shows that various geological materials have varying adsorption capability (Q_m). The present Q_m by deposited silt is 10.2564 mg/g which is similar, more or closer to some researchers' findings (Table 8). Q_m of this study is inferior to several other geological adsorbents. Also, do not use any acid, alkali, solvent (which may be harmful to health and the environment) or high temperatures (which spent energy) to create geological adsorbents. Consequently, the application of deposited silt, without any other adverse consequences, is cost-effective and environmentally safe.

4. Conclusion

This study evaluated the feasibility of employing deposited silt for Cd adsorption using the Taguchi method to determine the optimum removal condition through 25 trials. The results showed that Cd removal varied from 62.1 to 99.1 %, depending on how the controllable factors were combined. The influencing extent of the controllable factors of Cd removal in descending order was $\text{pH} > \text{ST} > \text{AD} > \text{IC}$. In other words, with a 88.17 % contribution, the pH of the solution was the most influencing element, while the initial concentration of Cd was the lowest mean 0.60 %. Deposited silt has a maximum adsorption potential of Cd of 10.25 mg/g. Compared to Freundlich isotherm for Cd removal, the Langmuir isotherm model is better at defining the Cd adsorption on deposited silt with R^2 value is 0.9993. Also adsorption kinetics shows that the equilibrium data were ideally suited to the Pseudo second-order model by means of R^2 value is 0.9978. In this research, the findings

showed that the deposited silt is really a promising alternative for the successful removal of Cd from aqueous solution.

Declarations

Author contribution statement

Sandeep R. Korake: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Pradip D. Jadhao: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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