

RECLAMATION OF PCB WASTEWATER

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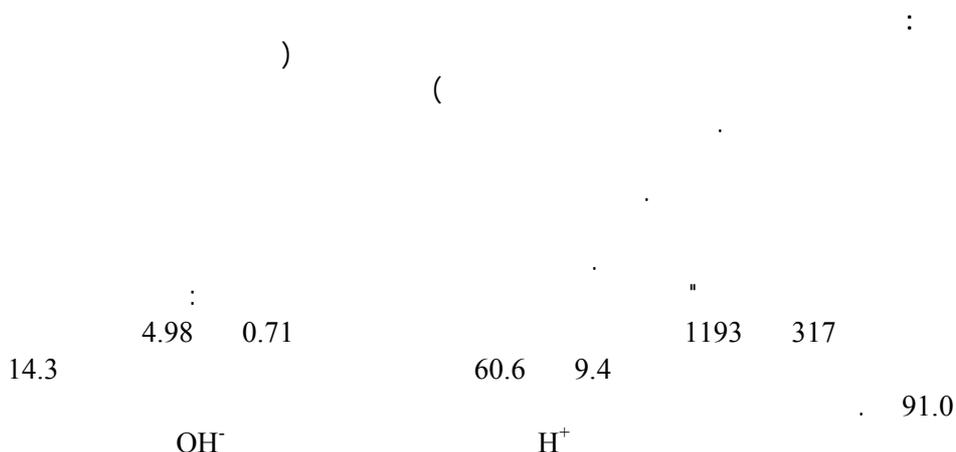
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Abstract:

Wastewater from electronic printed circuit board (PCB) factories was subjected to lab-scale ion exchangers of two types: strong acid cation followed by weak base anion exchanger. The experimental investigation was directed to study the ion exchanger performance in terms of three different parameters namely (TDS, feed rate and bed depth). Box-Wilson composite rotatable design was adopted in designing the experiments. Breakthrough times of (PCB) wastewater were studied through TDS ranged between 317 to 1193 ppm, feed rate ranged between 0.712 to 4.980 l/h, and bed depth of cation exchanger ranged between 9.4 to 60.6 cm and anion exchanger ranged between 14.3 to 91.0 cm.

Simulation the effect of the studied variables through their pre-designed ranges in terms of breakthrough time by 2nd order polynomial equation was obtained. In general, the performance and characteristics of adopting two bed deionizers (cation and anion beds) was proved efficient for the removal of the ionic contaminants and not less than 95 % of wastewater is recycled. In addition, the research considers the treatment of highly metals content regenerant solution out coming from reclamation system to minimize its metal content. The reclamation of wastewater was studied in terms of breakthrough time (i.e., the leakage of the cations).

Key wards: Wastewater, Ion Exchange, TDS, Feed Rate, Bed Depth.



Introduction

The disposal of wastewater is of widespread national concern. Water conditioning and wastewater treatment have long been essential functions of communities in present time due to the limited amount of the available water. Because of this it is important to find a solution to this problem such as: reuse of wastewater by using closed system, control of pollution, and if feasible, recovery of by-product to lessen the expense of treatment and to keep pollution at minimum levels. Wide range of ions may be removed from waste by ion-exchange resins. As the name implies, ion exchange works by

exchanging undesirable cations or anions in solution with less harmful ones. The ions are not destroyed but rather are removed from the waste stream and concentrated on the resin, where they can be more easily handled^(1,2).

Ion exchangers have been used for recovery of metals from plating baths restoring plating solutions which are contaminated with metals, and for removing of toxic metals from wastes either for reuse of water or prior discharging the water⁽³⁾. Ion exchange technology was applied in many studies to treat for example nickel ion from plating wastewater which contains heavy metal, bringing environmental problems such as chromium, zinc, copper, and lead⁽⁴⁾. It is used to further improve the removal efficiency of the color, Fe concentration, conductivity, alkalinity and total dissolved solids (TDS)⁽⁵⁾. Deionization removes all of ions from the water, leaving only non-ionic materials in solution⁽⁶⁾.

The ion exchange process is an alternative technique for application

in the treatment of industrial wastewater containing heavy metals and indeed it has proven to be very promising in the removal and recovery of valuable species⁽⁷⁾. It has also been used to remove specific impurities, and to recover valuable trace metals like chromium, copper, lead, cadmium, and nickel, from industrial waste discharges⁽⁸⁾. Ion exchangers are insoluble solid particles which are either naturally occurring inorganic zeolite or synthetically produced organic resins⁽⁹⁾. Most of the polymer bases used for ion exchange resins in beads form is the most widely utilized materials in many fields of science and industry^(10,11). The main types of synthetic ion exchangers were obtained by polymer-analogous reactions performed on porous S-DVB copolymers^(12,13). These resins have been classified based on the charge in the exchangeable counter ion (cation exchanger or anion exchanger) and the ionic strength of the bound ion (strong exchanger or weak exchanger)⁽¹⁴⁾.

In order to minimize the volumetric discharge containing the metals as well as the costs of purifying large quantities of wastewater from printed circuit board factory, a complete reclamation and wastewater treatment are decided to be investigated. Furthermore, the treatment of high metal content regenerant solution out coming from reclamation system to minimize the volumetric discharge was incorporated.

Experimental Work

Studying the performance of deionized exchangers at different (TDS, flow rates, and ion exchanger

heights) for cation and anion was conducted. Experiment duration (i.e., breakthrough time detection) was considered when the effluent stream reads electric conductivity of 40 $\mu\text{s}/\text{cm}$. The average conductivity of the collected water through run duration was around 10 to 15 $\mu\text{s}/\text{cm}$ (i.e., TDS content between 5 to 7.5 ppm). The accuracy of electric conductivity readings was established by generating a calibration curve that interprets NaCl concentration in terms of conductivity reading. Correspondingly, these readings are found equal to twice the value of TDS. These readings are listed in Table (1). Sodium chloride of 99 % purity was used in calibrating the TDS values with electric conductivity readings.

The performance of the ion exchangers towards wastewater was studied over two months by withdrawing samples from final pit. The analyses of the samples are shown in Table (2). From these analyses it seems that the Cu^{++} was the most probable pollutant.

The currencies of events through the experimental work are as follows:

- (1) Removing the toxic heavy metals by ion exchangers;
- (2) Concentrating them by regeneration solution;
- (3) Precipitating the small volumes of concentrated solution as hydroxides by lime.

Monitoring the TDS concentration in the treated water was carried out by measuring the electric conductivity of the effluent stream. The concentrations of other ions such as Ca^{++} , Mg^{++} , Cl^- , etc. are detected by other instrumental techniques. Table (3) shows the properties of produced water after

treating with two kinds of ion exchangers.

The precipitation of toxic heavy metals especially Cu^{++} , which is concentrated by acidic solutions from cation exchanger, was also studied. The studied conditions are Cu^{++} concentrations ranged between 293 to 1707 ppm and pH value between (8.6) to (11.4).

Chemicals and Instrumental Apparatus:

4% HCl and 4% NaOH solutions were used for the regeneration of cation and anion exchangers respectively. Strongly acidic cation exchanger of type IR – 120, mesh size 14-50 and weakly basic anion exchanger of type Lewatit C, mesh size 20-50 were used.

The following apparatus were used for measuring the cation and anion concentrations in wastewater:

1. Flame Atomic Absorption Spectrophotometer, Type Shimadzu AA – 680 G. Japan, was used to determine concentration of Cu^{++} , pb^{++} , Sn^{++} , pd^{++} , Na^+ , Ca^{++} , Mg^{++} , ...etc.
2. Flameless Atomic Absorption Spectrophotometer with graphite furnace atomizer, Type Shimadzu GFA-4B Japan, was used to determine the concentration of Cu^{++} , pb^{++} , Sn^{++} , Pd^{++} , Na^+ , Ca^{++} , ...etc. when the concentration of the ions is less than 0.01 ppm.
3. pH meter, Type Titro-Processor 686 Metrohm Swiss made.
4. Conductivity meter, Type 83 Copenhagen Denmark made, ranged between 0 to 3000 $\mu\text{s}/\text{cm}$.
5. Conductivity meter, Type Seral Seradest 5600 U. S. A., ranged between 0 to 20 $\mu\text{s}/\text{cm}$.
6. Conductivity meter, Type WTW LF91 Germany, ranged between 0 to 9000 $\mu\text{s}/\text{cm}$.

7. Turbidity meter, Type HACH Company Model 43900 was used to test concentration of SO_4^- , and Cl^- .
8. Gas Chromatograph, Type Hewlett Packard 438A U. S. A., Flame Ionization.

The experimental rig consists mainly of two deionization columns (i.e., cation exchanger and anion exchanger). These columns were incorporated with dosing pumps. A schematic diagram of the apparatus was shown in Fig (1). Specification of the columns, valves and dosing pumps are listed below:

1. Germany Schott glass columns of 50-cm long and 2.54 cm diameter.
2. Glass columns of 90-cm long and 2.54 cm diameter.
3. Plastic (TFE) valves to control opening and closing, direction into column to another.
4. Plastic barrels and container of different capacity.
5. Dosing pumps: CFG Prominent Electronic, Type B02-035 Sweden of flow rate range 0-34.92 lit/h.
6. Dosing pumps: Prominent Electronic, Type E 0407 GmbH Sweden, of flow rate range 0-6.3 lit/h.

Conditioning of the Ion Exchangers:

Columns C_1 and C_2 are packed with strongly acidic cation exchanger and weakly basic anion exchangers respectively with bed volume of two-third of the column volume (i.e., exchanger packed with no bubbles exist between its particles). The two columns were soaked with deionized water.

Back Washing

The ion exchangers in columns C_1 and C_2 were washed with flow rate of

10-bed volume/h. The back washing was lasted from 10 to 15 minutes using industrial water to get ride off fine particles and dirt. The benefit of this process is to rearrange the particles of the ion exchanger inside the column (uniformity of packing). Water for washing was pumped by pump No. 1.

Regeneration:

Regeneration of the Cation Exchanger

Regeneration of the cation exchanger was carried out by acid solution, 4 % HCl. The acid solution was pumped from tank T_2 through pump No.2 downward column C_1 with flow rate of 4-bed volume. The regeneration was lasting 75 minutes.

Rinse Process:

Slow Rinse

Industrial water is pumped downwards column C_1 via pump No.1 with flow rate of 4-bed volume/h. The slow rinsing step was lasted 15 minutes.

Quick Rinse

Industrial water is pumped downwards column C_1 via pump No. 1 with flow rate of 8 bed volume/h. The quick rinsing was lasted for 30 minutes.

Regeneration of the anion Exchanger

(NaOH) with concentration of 4 % is pumped from tank T_3 via pump No.3 downwards column C_2 with flow rate of 4 bed volume/h. The regeneration of anion exchanger was lasted 45 minutes.

Rinse Process:

Slow Rinse

Industrial water is pumped downward column C_1 via pump No.1 then inside column C_2 with 4 bed volume/h. The rinsing step was lasted 15 minutes.

Quick Rinse

Industrial water is pumped downward by pump No.1 into column C₁, then into column C₂ with a flow rate of 8 bed volume/h. This step lasted for 30 to 45 minutes until the residual conductivity of 40 µs/cm was detected.

Waste Water Flowing Stage:

Wastewater is pumped by pump P₁ from tank T₁ inside column C₁ (cation exchanger) and then inside column C₂ (anion exchanger) with different flow rates. The flowing of solution was kept during the experiment with continuous monitoring of the conductivity of the effluent stream until breakthrough point of conductivity of 40 µs/cm was detected.

Experimental Design:

The application of the experimental design for planning the experiments required to examine the system, will extract the information from pre-existing data by using a statistical method to interpret the results in regular form with the minimum number of observations⁽¹⁸⁾. Also, the polynomial representation will facilitate the analysis of the system by many techniques, such as optimization of process conditions, required for the maximum value of the objective function^(18,19).

An experimental design for fitting a second-order model must have at least three levels for each factor so that the model parameters can be. The proper technique for planning a system of more than three variables is “Central Composite Rotatable Design”. The total number of treatment combinations is equal to $(2^k + 2k + 1)$, where k is the number of variables, plus additional further treatments to take the lack of fit and experimental error into

account. This designs consists of 2^k fractional (i.e. coded to the usual ± 1 notation) augmented by 2k axial points, i.e. $(\pm \alpha, 0, \dots, 0), (0, \pm \alpha, 0, \dots, 0), (0, 0, \pm \alpha, \dots, 0), \dots, (0, 0, \dots, \pm \alpha)$ and center points $(0, 0, 0, \dots, 0)$. A preliminary step is to set up the relationships between the coded levels and the corresponding real variables.

These relationships are as follows:-

$$X_{\text{coded}} = \frac{[X_{\text{actual}} - X_{\text{center}}]}{\left[\frac{X_{\text{center}} - X_{\text{min.}}}{\sqrt{k}} \right]} \dots\dots\dots(1)$$

The value of (α) must be $2^{k/4}$ in order to make the design rotatable⁽¹⁹⁾.

The study was devoted to test the effect of process variables on breakthrough time (leakage). The experimental work for demineralized water production using wastewater was designed in the following experimental ranges:

- (1) Total dissolved salts (TDS) from 317 to 1193 ppm.
- (2) Feed rate of wastewater from 0.712 to 4.98 liter/hr.
- (3) Bed depth for cation exchanger from 9.355 to 60.64.

The working ranges of coded and corresponding real variables are listed in Table (5). According to experimental design, there are (19) experiments in a sequence shown in Table (6) where the coded values are +1.732, -1.732, 0. The codes represent the maximum, minimum and average values respectively.

Response Surface Methodology:

In most response surface methodology (RSM), the form of the relationship between the response

and the independent variables is usually a second order polynomial in some region of the independent variables. It is assumed that the independent variables are continuous and controllable by the experimenter with negligible error.

$$Y = B_0 + \sum_{i=1}^k B_i X_i + \sum_{i=1}^k B_{ii} X_i^2 + \sum_{i,j} B_{ij} X_i X_j + \varepsilon$$

If the fitted surface is an adequate approximation of Y then analysis of the fitted surface will be approximately to analysis of the actual system. The model parameters can be estimated most effectively if proper experimental designs are used to collect the data and customarily method of least squares is used to estimate the parameters in the approximating polynomial⁽¹⁹⁾.

Postulating the Mathematical Model:

To postulate the best formal of the proposed models, the experimental data in Table (7) was fitted to estimate the coefficients of the proposed models.

Results and Discussion:

Estimation the Coefficient of the Proposed Model:

Using the experimental data, the coefficients of the 2nd order polynomial were estimated by statistical software. The number of iterations was terminated when the proportion of variance accounted for was equal to 0.96075 and the correlation coefficient (R) was equal to 0.98018. Correlating the three studied variables with break through time the following models were determined:

$$Y = 6.766621 - 3.296712X_1' - 5.737603X_2' + 4.142875X_3' + 0.820419X_1'^2 + 3.078727X_2'^2 - 0.254468X_3'^2 + 1.136005X_1'X_2' - 1.656272X_1'X_3' - 1.965275X_2'X_3'$$

Break through time (h):

Optimum operating conditions at maximum breakthrough time were determined using pattern move Hooks and Jeeves optimization technique and they were equal to:

Maximum Breakthrough Time
X₁' = 317 ppm, X₂' = 0.712 l/h, X₃' = 60.64 cm

To emphasize the effect of each variable on breakthrough time of Al-Zawraa wastewater clearly and individually, each variable was studied separately from the other variables as they kept at constant values (i.e. optimum conditions). As shown in Figs (2) to (4) the effects of studied variables (i.e., TDS concentration coded as X₁, flow rate coded as X₂ and bed depth coded as X₃) on the breakthrough time were investigated. These figures indicate that the breakthrough time of the ion exchanger decreases with higher TDS and flow rate while longer breakthrough time was expected with longer bed height. The reasons for these characteristics are attributed as follows:

1. With higher TDS, the concentration of ions in solution increases that raises the mass transfer rate through the film until it exceeds the diffusion rate through the resin beads. Then diffusion through the resin becomes the controlling factor and the system is said to exhibit particle controlled kinetics, which is slower process. This condition means that the leakage curve is spread out over

deeper reaction zone. If this condition is happened it leads to shorter exhaustion time and lower operating capacity.

2. If the flow rate is slow enough, equilibrium is established as the solution reaches a new layer of the resin that means the wave front is only slightly diffuse as a result of each successive layer of resin being almost completely exhausted before leakage occurs. As flow rate increases, equilibrium is no longer reached and the exhaustion curve is spread out over deeper reaction zone which has a smaller an earlier breakthrough point. Furthermore, the curve tends to flatten (i.e., no further tendency to decrease) at higher flow rate. This was attributed that if the flow rate is slow, the diffusion rates through the resin mass are much greater than that through the surrounding film. The film thus controls the rate of exchange, and the process exhibits film controlled kinetics. If the flow rate is increased further, the mass transfer through the film rises until exceeds the diffusion rate through the resin beads. Then, diffusion through the resin becomes the controlling factor, and the system is said to exhibit particle controlled kinetics where no influence might attribute from further increase in flow rate.

3. The operating capacity is defined as the proportion of total capacity used during the exchange process. It can amount to a large or small proportion of the total capacity and depends on a number of process variables including depth of resin bed. It was simply observed that the longer the column, the greater is the operating capacity of the resin and

consequently later breakthrough time which is simply attributed to the deeper is the reaction zone.

To study the interaction between the studied variables, Figs (5) to (7) were monitored. Figure (5) shows the interaction effect between flow rate and TDS concentration. In this figure it seems that no interaction had been noticed, besides, the effect of both variables had come in the direction of decreasing the breakthrough time with increasing flow rate and TDS concentration. Figure (6) shows the interaction effect between bed depth and TDS concentration. Herein, the concentration of TDS almost counterbalance the effect of bed height especially at the highest level of TDS since no significant variations in breakthrough time was observed with increasing bed height. Figure (7) shows the interaction effect between flow rate and bed depth. Both variables tend to affect the breakthrough time in opposite direction but it seems that the flow rate has the most significant effect on breakthrough time in comparison to the bed height.

Conclusions:

The following conclusions can be pointed out from this study:

1. Study the individuality of wastewater from Al-Zawrra Company by ion exchangers three variables (i.e., TDS, flow rate and bed depth) had been correlated with breakthrough time that adequately describe the characteristic performance of the ion exchanger.
2. It was shown that the studied three variables affect the breakthrough time in following sequence: $X'_2 > X'_3 > X'_1$.

3. It seems that increasing the total dissolved concentration leads to lesser breakthrough time or breakthrough time is inversely related to concentration i.e., the breakthrough time was decreased with increasing the inlet concentration of total dissolved solids of Al-Zawraa Company wastewater.
4. Pronounced effect of bed depth on the breakthrough time was found.
5. The effect of flow rate on breakthrough time indicates that higher flow rate leads to lesser breakthrough time which means higher amounts of total dissolved solids adsorbed at lower flow rate for a given time besides it may contribute to lower residence time inside the column.
6. Higher concentration of total dissolved solids leads to higher concentration of ions in solution that resulted to higher mass transfer rate through the film until it exceeds the diffusion rate through the resin beads and consequently the system is exhibited particle controlled kinetics that means deeper reaction zone (a condition that leads to shorter exhaustion time).
7. With slow flow rate, it seems that the wave front is only slightly diffuse as a result of each successive layer of resin being almost completely exhausted before leakage occurs and resulted to earlier breakthrough point till no tendency to decrease at higher flow rates where the process exhibits particle controlled kinetics where no influences might contributed from further increase in flow rate.

Nomenclature:

K	No. of variables
TDS	Total Dissolved Solids
$X'_1, X'_2,$ and X'_3	Coded variables for Al-Zawraa Wastewater experimental investigation represent TDS concentration, flow rate and bed depth respectively

References

- [1]. Danny D. R., "Fundamentals of Environmental Engineering", 1999.
- [2]. Paul L. B., "Pollution Prevention: Fundamental and Practice", McGraw Hill Companies, 2000.
- [3]. ABB Instrumentation, "Ion Exchange Simply Explained", Technical Support Department, May, 1999, (Internet).
- [4]. Tae-Hyoung Eom, Chang-Hwan Lee, Jun-Ho Kim and Choul-Ho Lee; Desalination, volume 180, issues 1-3, 15 August 2005, 163-172.
- [5]. Raghu S. and Ahmed Basha C.; Journal of Hazardous Materials, Article in Press, Accepted 30, March, 2007 (Internet).
- [6]. Remco Engineering, "Power Purge Deionization Systems High Efficiency DI", website: <http://www.remco.com/ix.htm>, 2000, (Internet).
- [7]. Sofia A. Cavaco, Sandra Fernandes, Margarida M. Quina and Licinio M. Ferreira; Journal of Hazardous Materials, Volume 144, issue 3, 18 June 2007, 634-638
- [8]. Rao C. S. "Environmental Pollution Control Engineering", New Delhi, New Age International Limited, 1994.
- [9]. Remco Engineering, "Ion Exchange",

<http://www.remco.com/ix.htm>.2001, (Internet).

- [10.] Alberti G, Gasciola M, Constantino U; Encyclopedia of Analytical Chemistry [M], London, Academic Press, 1995, 4, 2273.
- [11.] Luca C; Encyclopedia of Separation Science [M], London, Academic Press, 2000, 4, 1617.
- [12.] Dragan S, Csergo D, Manolescul, et al.; Reactive Polymers, 1987, 5, 123.
- [13.] Dragan E S, Avram E, Axente D, et al.; J Polym Sci., Part A, PolymChem, 2004, 42, 2451.
- [14.] Aldrich, "Ion Exchange Resins: Classification and Properties", Aldrich Technical Bulletin AL-142, Jan, 2002, (Internet).
- [15.] Ullmans,"Encyclopedia of Industrial Chemistry", VCH, 1989.
- [16.] Cox D. R., "Planning of Experiments", New York, 1958.
- [17.] Box and George E. P., "Statistics Experimenters", New York, 1978.

Table (1) Different concentrations of TDS and their
Corresponding conductivity readings

Sample No.	NaCl Concentration (ppm)	Conductivity ($\mu\text{s}/\text{cm}$)	Temperature ($^{\circ}\text{C}$)
1	1500	2970	24 – 25
2	1200	2402	24 – 25
3	900	1793	24 – 25
4	450	912	24 – 25
5	750	1500	24 – 25
6	300	615	24 – 25
7	150	301.7	24 – 25
8	75	155	24 – 25
9	30	62	24 – 25
10	15	30.5	24 – 25
11	7.5	15.0	24 – 25
12	1.5	3.0	24 – 25
13	0.75	1.5	24 – 25

Table (2) Analyses of Electronic Printed Circuit Board wastewater
from
Al-Zawraa Company

Kind of Test	Result	Allowable Limits (Disposal into River)
pH	6.2 – 7.4	10 – 10.6
TDS, ppm	600 – 932	1200
TSS, ppm	0 – 16	<30
SO ₄ ⁻² ppm	295 – 400	<500
NO ₃ ⁻ ppm	1.3 – 1.5	<50
Cl ⁻ ppm	132 – 216	<400
Cu ⁺² ppm	0.5 – 25	<1
Pb ⁺⁺ ppm	0.04 – 0.4	<0.1
Pd ⁺⁺ ppm	Nil	
Fe ⁺⁺ + Fe ⁺³ ppm	0.003	
Mn ⁺² ppm	0.008	
Sn ⁺² ppm	0.01 – 0.1	
Ca ⁺⁺ ppm	140	
Mg ⁺⁺ ppm	38	
T. H ppm	480 – 608	700
CO ₃ ppm	90 – 130	
Na ppm	76 – 115	

Table (3) Properties of produced deionized water from wastewater of Al-Zawraa Company

Test	Result
pH	7
Na ⁺	1.32 – 4.6 ppm
Cl ⁻	2.2 – 7 ppm
Cu ⁺²	0.001 – 0.008 ppm
pb	Nil
Sn	Nil
Pd	Nil
TDS	Nil (not sensitive)

Table (4) Valves positions in operation, cation backwash and anion Backwash steps

	Process	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Operation	C	O	O	C	C	C	C	C	O	C	O	C	C	C	C	C	O	
2	Backwashing Cation	C	O	C	O	O	C	O	O	C	C	C	C	C	C	C	C	C	C
3	Backwasing Anion	C	O	O	C	C	C	C	C	O	C	C	O	O	C	O	O	C	
4	Regeneration Cation	O	C	O	C	C	O	O	O	C	C	C	C	C	C	C	C	C	C
5	Rinsing Cation	C	O	O	C	C	O	O	O	C	C	C	C	C	C	C	C	C	C
6	Regeneration Anion	C	C	C	C	C	C	C	C	O	O	C	C	O	O	O	O	C	C
7	Rinsing Anion	C	O	O	C	C	C	C	C	O	C	O	C	C	O	O	O	C	

Table (5) Working Range of Coded and Corresponding Real Variables

Coded Level	TDS (ppm)	Feed Rate (liter/hr)	Bed Depth (cm)
-1.732	317	0.712	9.355
-1	500	1.62	21.25
0	750	2.85	37.5
+1	1000	4.08	53.75
+1.732	1193	4.98	60.64

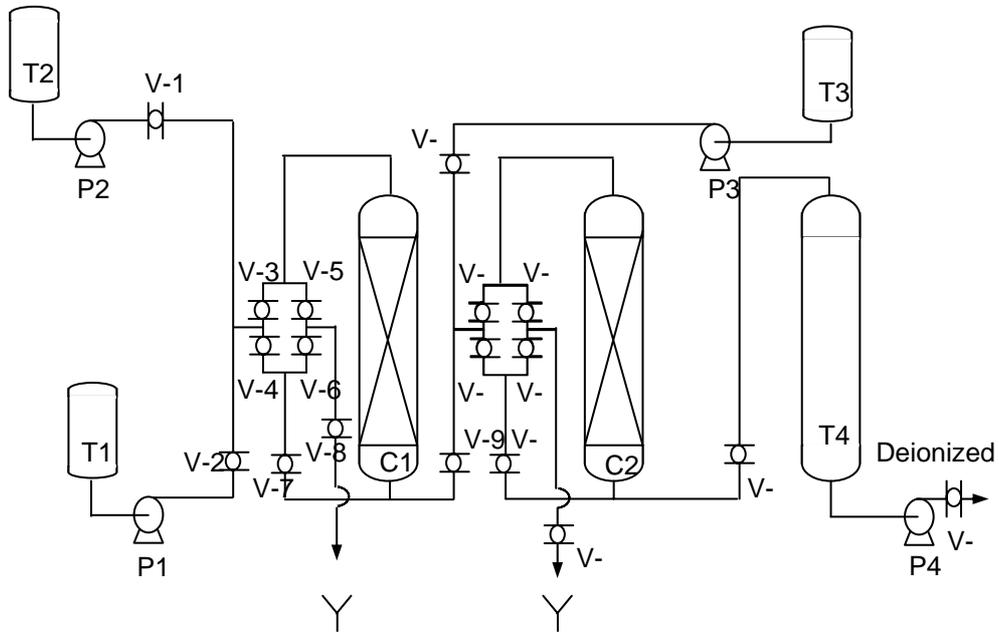
Table (6) Sequence of Experiments According to Central Composite Design

Exp. No.	Coded Variable			Real Variable		
	X ₁	X ₂	X ₃	TDS Conc. (ppm)	Feed Rate (l/h)	Bed Depth (cm)
1	+1	+1	+1	1000	4.08	53.75
2	+1	+1	-1	1000	4.08	21.25
3	+1	-1	-1	1000	1.62	21.25
4	-1	+1	-1	500	4.08	21.25
5	-1	-1	+1	500	1.62	53.75
6	+1	-1	+1	1000	1.62	53.75
7	-1	+1	+1	500	4.08	53.75
8	-1	-1	-1	500	1.62	21.25
9	-1.732	0	0	317	2.85	37.5
10	0	-1.732	0	750	0.712	37.5
11	0	0	-1.732	750	2.85	9.355
12	1.732	0	0	1193	2.85	37.5
13	0	1.732	0	750	4.98	37.5
14	0	0	1.732	750	2.85	60.64
15	0	0	0	750	2.85	37.5
16	0	0	0	750	2.85	37.5
17	0	0	0	750	2.85	37.5
18	0	0	0	750	2.85	37.5
19	0	0	0	750	2.85	37.5

Table (7) Experimental breakthrough time

Exp. No.	Coded Variable			Real Variable			Exp. Breakthrough Time (h)	Pred. Breakthrough Time (h)
	X ₁	X ₂	X ₃	TDS Conc. ppm	Flow Rate (l/h)	Bed Depth (cm)		
1	1	1	1	1000	4.08	53.75	5.272	3.03
2	1	1	-1	1000	4.08	21.25	1.5	1.99
3	1	-1	-1	1000	1.62	21.25	5.09	7.26
4	-1	1	-1	500	4.08	21.25	3.51	3.00
5	-1	-1	1	500	1.62	53.75	27.75	28.34
6	1	-1	1	1000	1.62	53.75	14.56	16.17
7	-1	1	1	500	4.08	53.75	11.75	10.67
8	-1	-1	-1	500	1.62	21.25	9.49	12.82
9	-1.732	0	0	317	2.85	37.5	15.75	14.94
10	0	-1.732	0	750	0.712	37.5	29.85	25.94

		1.732						
11	0	0	- 1.732	750	2.85	9.355	1.46	-1.17
12	1.732	0	0	1193	2.85	37.5	4.15	3.52
13	0	1.732	0	750	4.98	37.5	3.60	6.06
14	0	0	1.732	750	2.85	60.64	12	13.18
15	0	0	0	750	2.85	37.5	6.7	6.76
16	0	0	0	750	2.85	37.5	6.82	6.76
17	0	0	0	750	2.85	37.5	6.8	6.76
18	0	0	0	750	2.85	37.5	6.75	6.76
19	0	0	0	750	2.85	37.5	6.76	6.76



Equipment List	
Item	Description
T1	Wastewater Tank
T2	HCl (4 %) Tank
T3	NaOH (4 %) Tank
T4	Deionized Water Tank
C1	Cation Exchanger Column

C2	Anion Exchanger Column
P	Dosing Pump

Fig (1) Flow sheet for Wastewater treatment

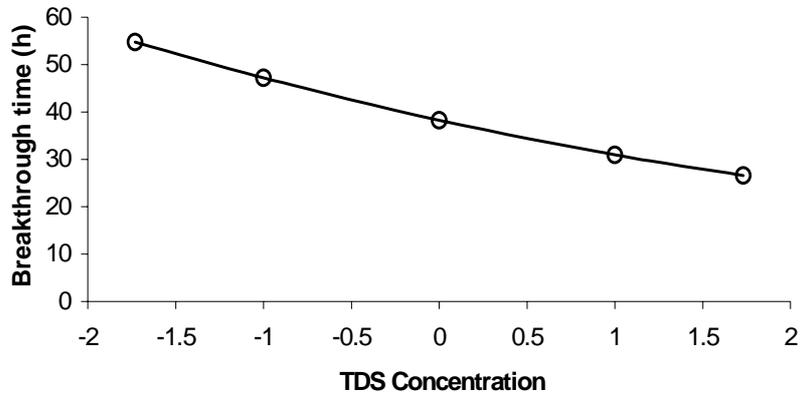


Fig (2) Effect of TDS concentration on breakthrough time

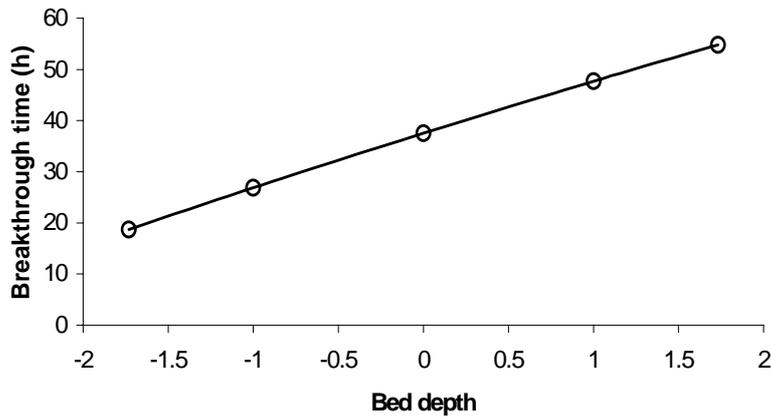


Fig (3) Effect of flow rate on breakthrough time

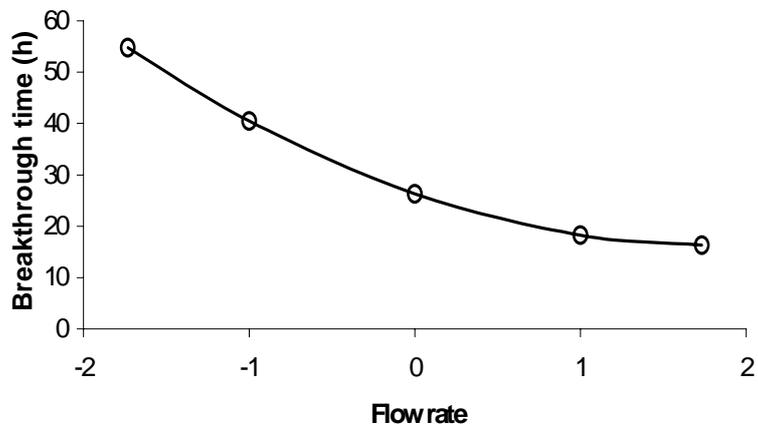


Fig (4) Effect of bed depth on breakthrough time

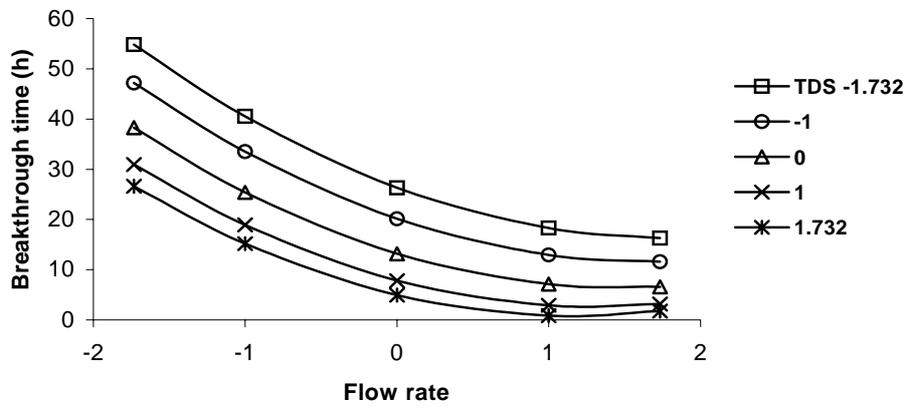


Fig (5) Effect of flow rate and TDS concentration on breakthrough time

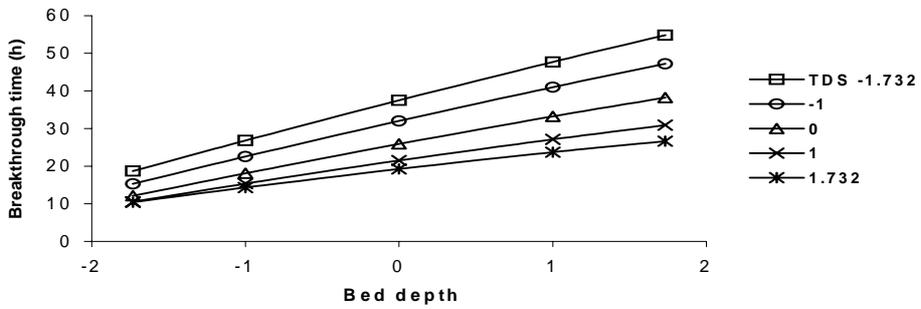


Fig (6) Effect of bed depth and TDS on breakthrough time

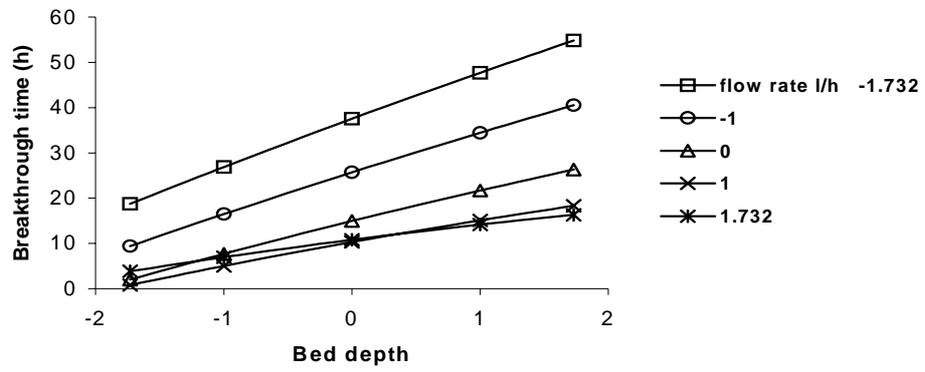


Fig (7) Effect of bed depth and flow rate on breakthrough time