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Characteristic Performance of Deionized Columns

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Abstract

The reclamation of makeup water is studied in terms of breakthrough time (i.e., the leakage of the cations). Makeup water was subjected to lab-scale ion exchangers of two types: strong acid cation and weak base anion exchanger. The experimental investigation was directed to study the ion exchanger performance in terms of four different parameters (i.e., copper concentration, total dissolved solids (TDS), feed rate and bed depth). Box-Wilson composite rotatable design was adopted in designing the experiments. Breakthrough times of the effluent stream are measured in terms of copper concentration of 2 to 25 ppm, TDS concentration of 250 to 1250 ppm, feed rate of 0.38 to 5.34 l/h and bed depth of 5 to 70 cm. Simulation the effect of the studied variables through their pre-designed ranges in terms of breakthrough time was done by 2nd order polynomial equation. In general, the performance and characteristic of adopting two bed deionizers (cation and anion beds) was efficiently recommended to remove the ionic contaminants and not less than 95 % of wastewater is recycled.

Keywords**:** characteristic performance, columns, reclamation, deionized.

Introduction

The fact that most ion exchange process is equilibrium reaction necessitating a continuous contacting of the exchanger with fresh electrolyte in order to drive the reaction to completion. The column technique a most widely used method for conducting ion exchange reaction. Column operation is like several batch reactors in series. The column operation is essentially an elaborate multiple batches wise technique in which the upper most portion of the column is constantly contacting fresh electrolyte whereas the lower portions contact the electrolyte not adsorbed by the upper exchanger. This procedure permits the exchanger bed to become fully exhausted at the top first and then gradually downward[1].

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[2]. Water treatment, however, is the most important application of ion exchange; the main areas of interest are water softening, de-mineralization or de-ionization (the product of high purity water)[3]. Deionization removes all of ions from the water, leaving only non-ionic materials in solution[4]. 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)[5]. Ion exchange is a chemical treatment process used to remove unwanted ionic species from wastewater. 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[6,7].

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[8]. It is used to further improve the removal efficiency of the color, Fe concentration, conductivity, alkalinity and total dissolved solids (TDS)[9]. 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[10]. In industrial practice where a solution flows through the ion exchange resin, equilibrium is not necessarily reached and the results are influenced by kinetic considerations. The rate-determining step of ion exchange is the diffusion of the mobile ions toward, from and in the resin phase, rather that the chemical reaction between fixed ions of the resin and mobile counter ions[11].

The present experimental investigation studies the most affecting parameters on ion exchanger performance. Studying the behavior of ionic exchangers was carried out at different concentration of Cu+2 ions, different TDS content, different flow rates, and different ion exchanger heights (cation and anion). Precipitation of ions of toxic heavy metals generated from regeneration was studied by adding 20 % CaO aqueous solution. These toxic heavy metals are precipitated as hydroxide. The operating conditions using aqueous solutions containing NaCl, CuSO4 are shown below. Selecting of salts of two kinds of ions Cu+2 and Na+ are recommended to study their influence on each other. This will give an idea about the behavior of the ion exchangers towards monovalent and divalent ions. Also the study is directed to consider the reclamation system through characterizing the performance of two bed deionizers (cation and anion beds) towards removing ionic contaminants. An experimental design is necessary to find useful relationships between controllable variables and observed response.

Experimental Work

Experimental design

The simplest experiment is a comparison of two things that differ in just one attribute. This sort of experiment obviously has a practical value, but it offers little insight. To gain such insight, more variables must or have to be considered whether there is a quantitative relationship between variable and response and what the form is, linear, quadratic, etc. Having established such a relation, the effect of other variables would examine in the same manner. Variables acting together may have a greater or smaller effect than individual variables acting alone. A response surface can be most efficient fitted if proper attention is given to the choice of experimental design[12].

The systematic method, which satisfies the above function with minimum number of experiments, is called "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[14]. This analysis will give description for the system by a correction in order to predict the effect regarding the change of variables on the objective function. 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[12,13].

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 estimated (i.e. variables are usually called factor and the particular value of the variable is called the level). 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 $\left(2^k + 2k + 1\right)$, where k is the number of variables, plus additional further treatments to take the lack of fit and experimental error into account. This design consists of 2^k fractional (i.e. coded to the usual $\pm$ 1 notation) augmented by 2k axial points, i.e. ($\pm\alpha$, 0, …,0), (0, $\pm\alpha$, 0, …,0), (0, 0, $\pm\alpha$, …, 0), ……, (0, 0, …, $\pm\alpha$) and center points (0, 0, 0, …, 0). A preliminary step is to set up the relationships between the coded levels and the corresponding real variables. These relationships are as follows (Box and George, 1978):-

$$x_{Coded} = \frac{\left\lfloor x_{actual} - x_{center} \right\rfloor}{\left[\dfrac{x_{center} - x_{\min.}}{\sqrt{k}} \right]} \tag{1}$$

Finally, the number of experiment (n) needed is estimated according to the following equation:

$$n = 2^k + 2k + 1 \tag{2}$$

The experimental trials using makeup water were designed to produce demineralized water through the following experimental ranges:

1. copper concentration between 5 to 25 ppm.
2. total dissolved salts (TDS) between 250 to 1250 ppm.
3. Flow rate of wastewater between 0.38 to 5.34 l/h.
4. Bed depth for cation resin between 5 to 70 cm and for anion resin between 7.5 to 105 cm.

According to Eq (1) the coded levels are related to the real variables as follows:

$$X_1 = \frac{C_C - 15}{5} \ldots\ldots\ldots\ldots(3), \quad X_2 = \frac{C_T - 750}{250} \ldots\ldots\ldots\ldots(4)$$

$$X_3 = \frac{F - 2.85}{1.23} \ldots\ldots\ldots\ldots(5), \quad X_4 = \frac{B - 37.5}{16.25} \ldots\ldots\ldots\ldots(6)$$

Where CC is the concentration of copper in ppm, CT is the total dissolve solid in ppm, F is the feed rate in l/h, and B is Bed depth of cation resin in cm.

The working ranges of coded and corresponding real variables are listed in Table (1). Accordingly, there are 28 experiments in a sequence shown in Table (2) where the coded values +2, -2, 0 represent the maximum, minimum and average values respectively.

Table 1 Coded and corresponding real variables

Coded Level	Cu Conc. (ppm)	TDS Conc. (ppm)	Feed Rate (l/h)	Bed Depth (cm)
-2	5	250	0.38	5.00
-1	10	500	1.62	21.25
0	15	750	2.85	37.50
1	20	1000	4.08	53.75
2	25	1250	5.34	70.00

Table 2 Sequence of Experiments

Exp. No.	Coded Variable				Real Variable			
	X_1	X_2	X_3	X_4	Cu^{+2} Conc. (ppm)	TDS Conc. (ppm)	Feed Rate (liter/hr)	Bed Depth (cm)
1	-1	-1	-1	-1	10	500	1.62	21.25
2	1	-1	-1	-1	20	500	1.62	21.25
3	-1	1	-1	-1	10	1000	1.62	21.25
4	1	1	-1	-1	20	1000	1.62	21.25
5	-1	-1	1	-1	10	500	4.08	21.25
6	1	-1	1	-1	20	500	4.08	21.25
7	-1	1	1	-1	10	1000	4.08	21.25
8	1	1	1	-1	20	1000	4.08	21.25
9	-1	-1	-1	1	10	500	1.62	53.75
10	1	-1	-1	1	20	500	1.62	53.75
11	-1	1	-1	1	10	1000	1.62	53.75
12	1	1	-1	1	20	1000	1.62	53.75
13	-1	-1	1	1	10	500	4.08	53.75
14	1	-1	1	1	20	500	4.08	53.75
15	-1	1	1	1	10	1000	4.08	53.75
16	1	1	1	1	20	1000	4.08	53.75
17	-2	0	0	0	5	750	2.85	37.5
18	2	0	0	0	25	750	2.85	37.5
19	0	-2	0	0	15	250	2.85	37.5
20	0	2	0	0	15	1250	2.85	37.5
21	0	0	-2	0	15	750	0.38	37.5
22	0	0	2	0	15	750	5.34	37.5
23	0	0	0	-2	15	750	2.85	5.0
24	0	0	0	2	15	750	2.85	70.0
25	0	0	0	0	15	750	2.85	37.5
26	0	0	0	0	15	750	2.85	37.5
27	0	0	0	0	15	750	2.85	37.5
28	0	0	0	0	15	750	2.85	37.5

Also, precipitation of heavy metals ions especially for copper ions from concentrated solution after regeneration was studied. The experiments were designed in the following ranges: -

1. Copper concentration between 293 to 1500 ppm.
2. pH value between 8.6 to 11.4.

The working ranges of coded and corresponding real variables are listed in Table (3). Accordingly, there are (12) experiments as listed in Table (4) where the coded values +1.414, -1.414, 0 represent the maximum, minimum and average values respectively.

Table 3 Working range of coded and corresponding real variables

Coded Level	Copper Concentration (ppm)	PH
-1.414	293	08.586
-1	500	09.000
0	1000	10.000
1	1500	11.000
1.414	1707	11.414

Table 4 Sequence of experiments

Exp. No.	Coded Variable		Real Variable		Cu (ppm)
	X_1	X_2	Copper Conc. (ppm)	pH	
1	-1	-1	500	9	0.66
2	-1	1	500	11	0.50
3	1	-1	1500	9	0.10
4	1	1	1500	11	0.50
5	0	0	1000	10	0.30
6	0	0	1000	10	0.35
7	0	0	1000	10	0.25
8	0	0	1000	10	0.27
9	1.414	0	1707	10	0.40
10	-1.414	0	293	10	0.75
11	0	1.414	1000	11.414	0.38
12	0	-1.414	1000	8.586	0.2

Operating conditions

Cu^{+2} concentration ranged between 5 to 25 ppm coded as X_1

TDS ranged between 250 and 1250 ppm coded as X_2

Flow rate ranged between 0.38 to 5.34 l/h coded as X_3

Bed height of cation ranged between 5 to 70 cm coded as X_4

Bed height of anion ranged between 7.5 to 105 cm

The breakthrough point was decided to be when the effluent stream reads 40µs/cm conductivity. The average conductivity of the whole produced water after each run was found equal to 10-15 µs/cm (correspond to TDS content of 5 to 7.5 ppm). Testing these experiments was characterized on periodical measurements of electric conductivity of the effluent stream. Each sample was measured three times and average value was considered. The TDS content was obtained by dividing the readings of the electric conductivity by two.

The experiments are conducted in following sequence: (1) removing the toxic 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 deionized water was carried out by measuring the electric conductivity of effluent whereas others ions concentrations such as Ca++, Mg++, Cl-, etc. are measured by other instrumental techniques.

Chemicals

The following chemicals are used:

- 4 % HCl solution for regeneration of cation exchanger.
- 4% NaOH solution for regeneration of anion exchanger.
- Strongly acidic cation exchanger, type IR – 120 of mesh size 14-50 (Rohm & Haas), Amberlite.
- Weakly basic anion exchanger Type Lewatit of mesh sizes 20-50 (Bayer), Lewatit.

Measuring Devices

The following instrumental apparatus are used:

- Flame & Flameless Atomic Absorption Spectrophotometer, Type Shimadzu AA – 680 G. Japan, was used to determine concentration of Cu++, Na+, Ca++, Mg++, …etc.
- pH meter, Type Titro-Processor 686 Metrohm Swiss made.
- Conductivity meter, Type 83 Copenhagen Denmark made, ranged between 0 to 3000 µs/cm.
- Turbidity meter, Type HACH Company Model 43900 was used to test concentration of SO4=, and Cl-.

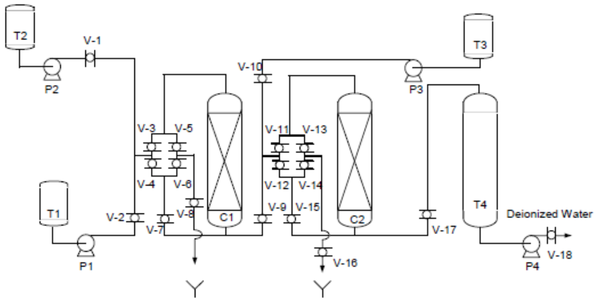
Apparatus

The experimental rig consists mainly of two columns for the cation and anion exchangers that were incorporated with dosing pumps. A schematic diagram of the apparatus was shown in Fig (1). The following specification of the columns, valves and dosing pumps are listed below:

Glass columns of 90-cm long and 2.54 cm diameter.

Dosing pumps: CFG Prominent Electronic, Type B02–035 Sweden

Flow rate 0 – 34.92 liter/hr



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

Experimental Procedure

Preparation Step

- Conditioning of the Ion Exchangers

Columns C1 and C2 are packed with strongly acidic cations exchanger and weakly basic anion exchangers respectively. The two columns were soaked with deionized water with bed volume of two–third of the column volume (i.e., exchanger packed no bubbles exist between its particles).

- Back Washing

Upward washing of the ionic exchangers (columns C1 and C2) with 10-bed volume/h using industrial water was lasted for 10 to 15 minutes to ensure entertainment of dirt and fine particles from the resin bed. Water for back washing was delivered using pump 1.

Regeneration Step

- Regeneration of the Cation Exchanger

Regeneration of the cation exchanger was carried out by 4 % HCl solution. The acid solution was pumped from tank T2 through pump 2 into column C1 downward with flow rate of 4-bed volume/h. Regeneration step was lasted for 75 minutes.

- Rinsing Step

Downward 4-bed volume/h industrial water was pumped into column C1 via pump 1. This step was lasted for 15 minutes, then rinsing with 8-bed volume/h for 30 minutes.

- Regeneration of the anion Exchanger

Downward 4-bed volume/h of 4 % NaOH solution was pumped from tank T3 via pump 3 into column C2. The regeneration was lasted for 45 minutes.

- Rinsing Step

Downward industrial water was pumped into column C1 and column C2 via pump 1 with 4-bed volume/h. The rinsing step was lasted for 15 minutes, then rinsing with 8-bed volume/h till a residual conductivity of 40 µs/cm was detected.

Flowing Stage/NaCl-$CuSO_4$ Solution

NaCl/$CuSO_4$ solution is pumped via pump 1 into column C1 (cation exchanger) and into column C2 (anion exchanger) with different feed rates. The flowing of solution was kept during the experiment until breakthrough point was detected at conductivity reading of 40 µs/cm.

Results and Discussion

Table (5) lists the experimental breakthrough time at the pre-designed operating conditions of the studied variables as listed in Table (3).

When the response or dependant variable influenced by independent variables, and when it is necessary to optimize this response, it is reasonably assumed that the independent variables are continuous and controllable by the experimenter with negligible error. In most RSM problems, the form of the relationship between the response and the independent variables is unknown. Usually, a second order polynomial in some region of the independent variables is employed. If the fitted surface is an adequate approximation then analysis of the fitted surface will be approximately to analysis of the actual system. Customarily, method of least squares is used to estimate the parameters in the approximating polynomial.

Using the experimental breakthrough times, the coefficients were estimated using nonlinear regression analysis technique via program software named Statistica. The number of iterations was terminated when the proportion of variance accounted for was equal to 0.977, and the correlation coefficient (R) 0.93149. Correlating the four variables with breakthrough time, the following model was determined:

$$\begin{aligned}Y = {} & 7.642605 - 0.744315X_1 - 4.172569X_2 - 7.962403X_3 + 4.209096X_4 \\ & - 0.677027X_1^2 + 0.658826X_2^2 + 4.862981X_3^2 - 0.666129X_4^2 + 1.015796X_1X_2 \\ & + 1.08517X_1X_3 + 1.030796X_1X_4 + 1.900425X_2X_3 - 1.333949X_2X_4 \\ & - 1.259574X_3X_4\end{aligned}$$

Optimum values at maximum breakthrough time were determined applying Hooks and Jeeves optimization technique and found equal to:

Maximum Breakthrough Time:

X_1 = 5 ppm, X_2 = 250 ppm, X_3 = 0.38 l/h, X_4 = 70 cm;

To emphases the effect of each variable on breakthrough time clearly and individually, each variable was studied separately (i.e. other variables are kept constant at optimum values). As shown in Figs (2) to (5), the effect of studied variables (i.e., copper concentration, total dissolved solids, and flow rate and bed depth) on the breakthrough time was investigated. These Fig.s indicates that the breakthrough time of the ion exchanger is decreased with increase in copper concentration, total dissolved solids concentration and flow rate and increased with bed height. The reasons for these characteristics are attributed as follows:

Various criteria influencing the general performance of ion exchange resin, however, relative selectivity of the resin for various ionic species has been considered into account in this situation since a strong cation resin operating in the H^+ form will preferentially exchange ions with different selectivity. It seems that earlier breakthrough time starts to occur with higher concentration of copper ions because Cu^{+2} ions start to replace Na^+ ions in the cation exchanger also SO_4^{-2} ions starts to replace Cl^- ions in the anion exchanger due to their higher selectivities that resulted in leak off the resin earlier.

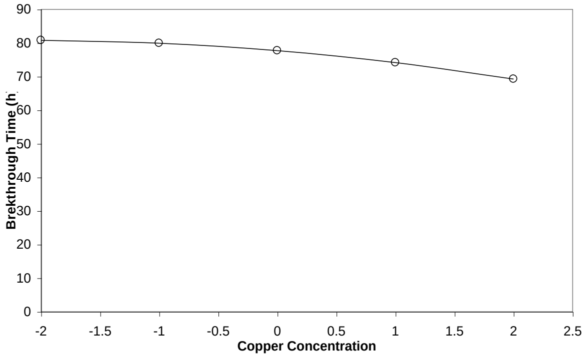


Fig. 2 Effect of copper concentration on the breakthrough time

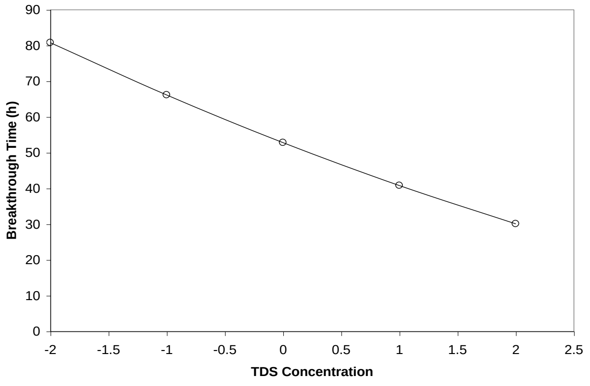


Fig. 3 Effect of TDS concentration on the breakthrough time

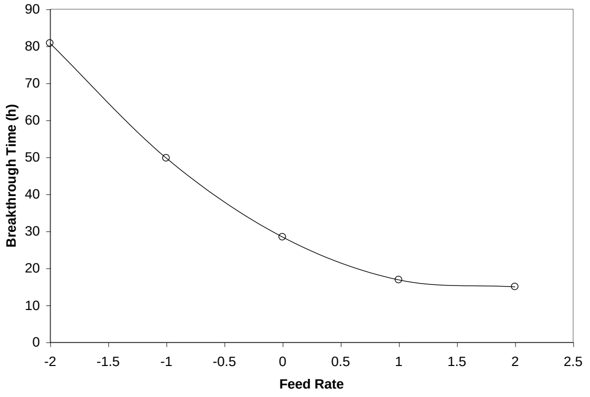


Fig. 4 Effect of feedrate on the breakthrough time

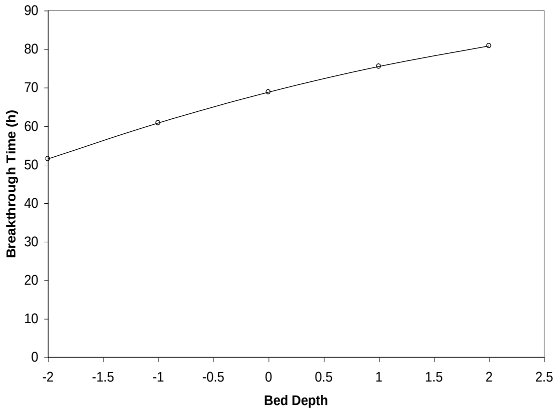


Fig.5 Effect of bed depth on the breakthrough time

With higher concentration of total dissolved solids, 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. 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.

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 operating capacity and earlier breakthrough point.

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 effects between the studied variables, Figs (6) to (11) were drawn. The effect of total dissolved solids concentration on the breakthrough time at different copper concentration was studied as represented in Fig (6). It shows that increasing the TDS concentration will decrease the breakthrough time as outlined above in studying the effect of TDS concentration on breakthrough time. This observation had come in accordance with Neretnieks justification who had previously pointed out that diffusion rate is controlled by the concentration gradient that takes longer contact time to reach adsorption equilibrium and exhaustion point for the case of low values of initial solute concentration(14). However, at higher concentration of TDS the resin leaks off earlier with lower copper concentration, which indicates reverse action of copper concentration on the breakthrough time (i.e., at coded value -2 corresponding to real value 5 ppm). This can be attributed to pronounce selectivity of Cu++ ions with respect to Na+ ions at higher concentration of Cu+2 that resulted in lately breakthrough time in comparison to lower concentration.

Fig. (7) demonstrates the interaction effect between flow rate and copper concentration. The breakthrough time decreases with increasing flow rate as previously monitored in Fig (4). Also, Fig (2) shows earlier breakthrough time with increasing copper concentration. However, same observation has been noticed at the extreme limit of flow rate (i.e., high flow rate) as found in Fig (6) that increasing copper concentration has shown lately breakthrough time. Once again, this can be attributed as declared above to the lower concentration of copper ions that resulted in faster uptake of Cu+2 ions and earlier breakthrough time.

Table 5 Experimental breakthrough time

Exp. No.	Coded Variable				Real Variable				Exp. Breakthro. Time (h)	Pred. Breakthro. Time (h)
	X_1	X_2	X_3	X_4	**Copper Conc. ppm**	**TDS ppm**	**Flow Rate l./hr**	**Bed Depth cm**		
1	-1	-1	-1	-1	10	500	1.62	21.25	10.75	15.18
2	1	-1	-1	-1	20	500	1.62	21.25	10.50	15.18
3	-1	1	-1	-1	10	1000	1.62	21.25	5.47	11.42
4	1	1	-1	-1	20	1000	1.62	21.25	5.30	7.73
5	-1	-1	1	-1	10	500	4.08	21.25	2.67	3.55
6	1	-1	1	-1	20	500	4.08	21.25	2.88	0.14
7	-1	1	1	-1	10	1000	4.08	21.25	1.20	-0.35
8	1	1	1	-1	20	1000	4.08	21.25	1.15	0.297
9	-1	-1	-1	1	10	500	1.62	53.75	28.9	34.47
10	1	-1	-1	1	20	500	1.62	53.75	28.8	30.84
11	-1	1	-1	1	10	1000	1.62	53.75	14.4	17.63
12	1	1	-1	1	20	1000	1.62	53.75	14.22	18.06
13	-1	-1	1	1	10	500	4.08	53.75	12.00	10.06
14	1	-1	1	1	20	500	4.08	53.75	12.00	10.77
15	-1	1	1	1	10	1000	4.08	53.75	5.20	0.81
16	1	1	1	1	20	1000	4.08	53.75	5.10	5.59
17	-2	0	0	0	5	750	2.85	37.5	7.69	6.42
18	2	0	0	0	25	750	2.85	37.5	7.38	3.45
19	0	-2	0	0	15	250	2.85	37.5	21.87	18.62
20	0	2	0	0	15	1250	2.85	37.5	3.90	1.93
21	0	0	-2	0	15	750	0.38	37.5	56.50	43.02
22	0	0	2	0	15	750	5.34	37.5	2.90	11.17
23	0	0	0	-2	15	750	2.85	5	0.57	-3.44
24	0	0	0	2	15	750	2.85	70	14.60	13.39
25	0	0	0	0	15	750	2.85	37.5	7.72	7.64
26	0	0	0	0	15	750	2.85	37.5	7.75	7.64
27	0	0	0	0	15	750	2.85	37.5	7.60	7.64
28	0	0	0	0	15	750	2.85	37.5	7.50	7.64

Fig. (8) demonstrates the interaction effect between bed depth and copper concentration. It seems that increasing the bed depth whatever copper concentration will increase the breakthrough time. This was attributed as previously outlined that the longer the column, the deeper is the reaction zone, and the greater is the operating capacity of the resin and consequently lately breakthrough time. But, herein it seems that the bed depth has pronounced effect on breakthrough time relative to copper concentration even though the two variables have opposite effect on breakthrough time, but still bed height tends to higher breakthrough time as if there is no influence of copper concentration on the breakthrough time.

Fig. (9) shows the interaction effect between flow rate and TDS concentration. In this Fig. it seems that no interaction had been noticed, besides, the effect of both variables had come in according with each other in the direction of decreasing breakthrough time with increasing flow rate and TDS concentration. Fig. (10) shows the interaction effect between bed depth and TDS concentration. Herein, the concentration of TDS almost counterbalance the effect of bed height on breakthrough time especially at highest concentration of TDS since no significant variations in breakthrough time was observed with increasing bed height.

Fig. (11) show 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 bed height.

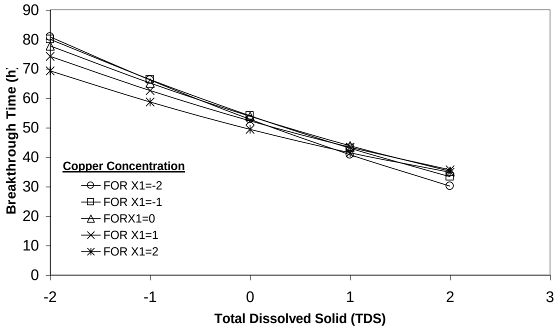


Fig. 6 Effect of copper concentration and TDS concentration on the breakthrough time

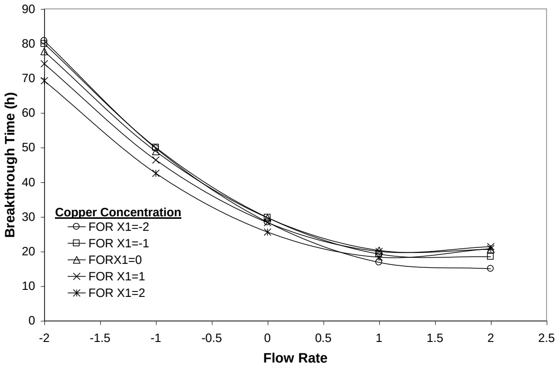


Fig. 7 Effect of copper concentration and flow rate on the breakthrough time

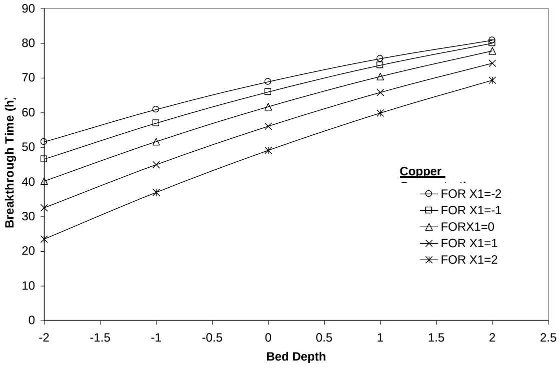


Fig. 8 Effect of copper concentration and bed depth on the breakthrough time

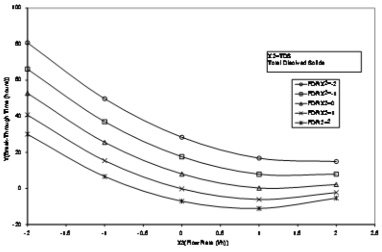


Fig. 9 Effect of TDS concentration and flow rate on the breakthrough time

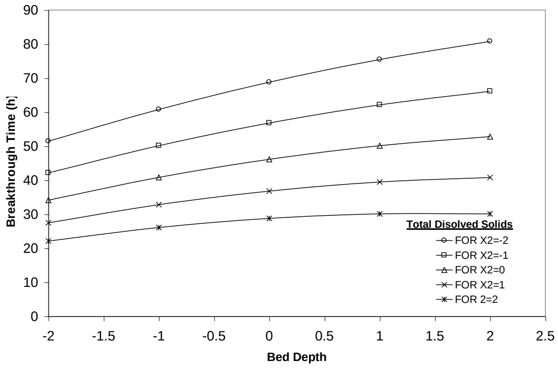


Fig. 10 Effect of TDS concentration and bed depth on the breakthrough time

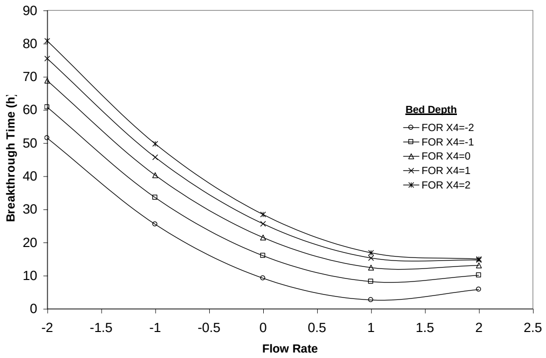


Fig. 11 Effect of bed depth and flow rate on the breakthrough time

Conclusions

The following conclusions can be pointed out:

1. It was shown that the studied four variables affect the breakthrough time in the following sequence:

$$X_3 > X_4 > X_2 > X_1$$

2. Pronounced effect of bed depth on the breakthrough time was found.
3. 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 contributes to lower residence time inside the column.
4. It was ascertained that various criteria influencing the general performance of ion exchange resin as the strong cation resin operating in the H^+ form will preferentially exchange ions with different selectivity that resulted in earlier breakthrough time with

increase in concentration of copper ions due to its higher selectivity in comparison to Na^+ ions.

5. Higher concentration of TDS 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.
6. 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 an earlier breakthrough point till no tendency to decrease at higher flow rates since the process exhibits particle controlled kinetics where no influences might contributed from further increase in flow rate.

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