A Numerical Approach for Determination of Parameters for Ion Exchange

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Summary: The removal of boron from wastewaters containing boric acid and borax has been investigated. A boron-specific resin Amberlite XE 243 has been effective in removing boron. The experimental results obtained were evaluated both graphically and mathematically.

The variation of boron concentrations in the effluents has been observed to depend, for various initial boron concentrations, Co on the ratio of filtrate volume to the volume accupied by resin. Consequently, an empirical equation relating effluent boron concentration, C to filtrate and resin volumes V and V_1, respectively has been developed, resulting $C = 2.34 \cdot 10^{-6} \cdot Co\ (V)^{-0.043}\ (V_1)^{2.79}$

Introduction

Boron compounds have long been used, in daily life as a part of disinfectants and detergents, and in various branch of industry including fuel production in space-crafts. Boric acid is produced from colemanite, and borax is produced from tincal in Turkey. Since sulphuric acid is used in the boric acid process, significant amounts of calcium sulphate is produced which should be separated by filtration and the resulting slurry is then discharged as a waste product causing environmental pollution. In borax production process, a tincal residue is obtained after condensation of aqueous solution as waste product.

The concentration of boron in waters used for irrigattion of crops has long been recognised as an important factor when considering possible toxic effects. Although, boron is an essential trace element for the nutrition of higher plants, concentrations exceeding 0.5 mg/1 boron in irrigation water may be harmful to certain crops. It is doubtful whether a continuous application of more than 0.5 mg/1 will not eventually produce toxic effects on plants. Many verieties of fuits, e.g. apples, plums and pears are listed among the most sensitive crops which can tolerate no more than 0.5-1 mg/l boron. However, sugar beet, onions, cabbages, carrots, can tolerate boron concentrations of 2-4 mg/1 while potatoes, peas, wheat and cats are among the crops listed as being able to withstand 1-2 mg/1 of boron [1,2].

Table 1: Effluent boron concentration at different pH values for the column with ID of 5 cm (v = 3 cm^3/min)

pH	C_o = 1600 mg/l	C_o = 500 mg/l	C_o = 50 mg/l
5	930	285	25
6	760	230	20
7	709	221	19
8	535	172	16
9.5	595	181	18
10.5	750	228	21
11.5	765	241	23
12.5	831	256	26

There is not any easy method for the removal of boron from waste waters boron removal by conventional biological treatment and chemical coagulation with lime, ferrous and aluminium salts has been proved to be ineffective [3]. The adsorption of boron by clays, soils and other minerals has been extensively studied by many investiagors [4]. In the present study, a broron specific resin Amberlite XE 243 was selected for the boron removal tests following the previous studies [5,6,7,8].

Results and Discussion

The boron concentrations in the effluents of adsorption column of D=2 cm 1D are presented in Table 2 for the original undiluted sample (C_o = 1600 mg/1). Similar tables are prepared for other set of initial boron concentrations and adsorption columns with various diameters, but values of these experimental results are not included in the text due to space limitation.

However, variation of dimensionless concentrations, C/C_o vs. V_1/AL (ratio of filtrate volume to resin volume) are shown in Figures 1,2,3 and 4, for inlet concentrations and column diameters of : C_o = 1600 mg/1 and D=2 cm, C_o = 500 mg/1 and D=5 cm and C_o = 50 mg/1 and D=10 cm, respectively.

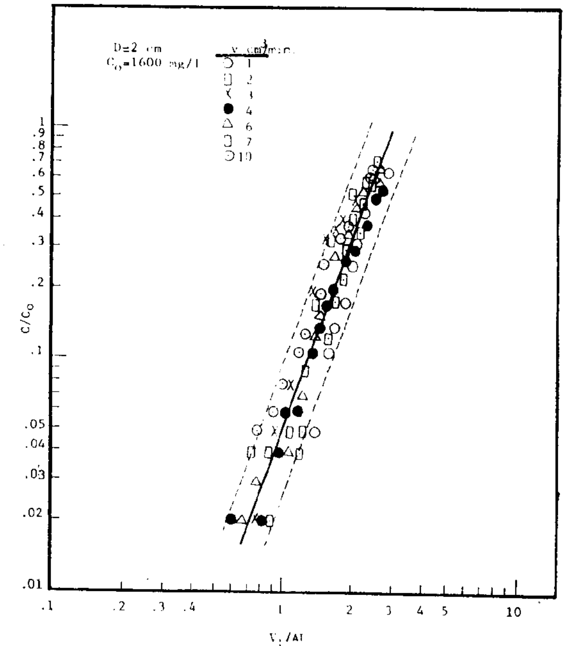


Fig. 1: Variations of V_1/AL vs. C/C_o

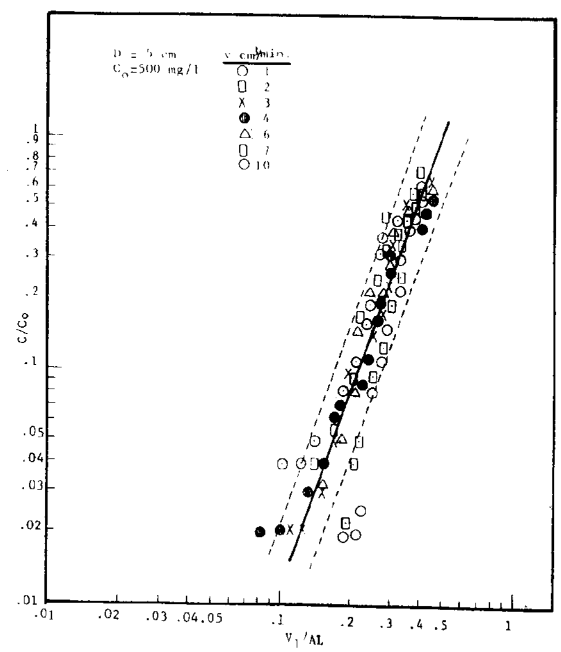


Fig. 2: Variations of V_1/AL vs. C/C_o

The effluent boron concentrations, C are subjected to regression and correlation analysis as functions of initial boron concentrations, C_o, volume of the columns occupied by resin (AL), and and flow rates (v) applied to ion exchange columns. Preliminary invesitgations indicated that dimen-

Table 2: (continued.)

Filtrate volume (ml)	Flow rates 6 cm^3/min B cons. (mg/1)	C/Co	7 cm^3/min Filtrate volume (ml)	B cons. (mg/1)	C/Co	10 cm^3/min Filtrate volume (ml)	B cons. (mg/1)	C/Co
6	18	0.01	7	42	0.03	10	58	0.04
12	18	0.01	14	42	0.03	15	64	0.04
18	32	0.02	21	48	0.03	20	64	0.04
24	34	0.02	28	59	0.04	25	76	0.05
30	46	0.03	35	64	0.04	30	80	0.05
36	62	0.04	42	80	0.05	35	94	0.06
42	62	0.04	49	142	0.09	40	128	0.08
48	112	0.07	56	287	0.18	45	176	0.11
54	206	0.13	63	544	0.34	50	206	0.13
60	254	0.16	70	667	0.41	55	302	0.19
66	448	0.28	77	692	0.43	60	448	0.28
72	575	0.36	84	835	0.52	65	574	0.36
84	752	0.47	91	948	0.59	70	608	0.38
90	848	0.53	99	1005	0.63	75	667	0.42
96	926	0.58	106	1103	0.69	80	769	0.48
102	1006	0.63				85	848	0.53
						90	976	0.61
						95	1071	0.67
						100	1134	0.71

Table 3: Values of the coefficents a and b in equation 1: $C/Co = a\ (V_1/AL)^b$ for different column diameters

D (cm) (1)	a (2)	b (3)	R (4)
2	0.0503	2.79	0.9933
5	8.331	2.79	0.9868
10	345.00	2.79	0.9850

As seen from this Table power of the variable (V_1/AL), i.e. b values in equation (1) is constant for various column diameters and equal to 2.79. However, coefficient a increases with an increase in column diameter, D. Again graphical analysis of, a, values vs. resin volumes, has given a straight line in Fig. 5 which can be represented by following relationship:

$$a = 2.34 \cdot 10^{-6} \cdot (AL)^{2.747} \quad (2)$$

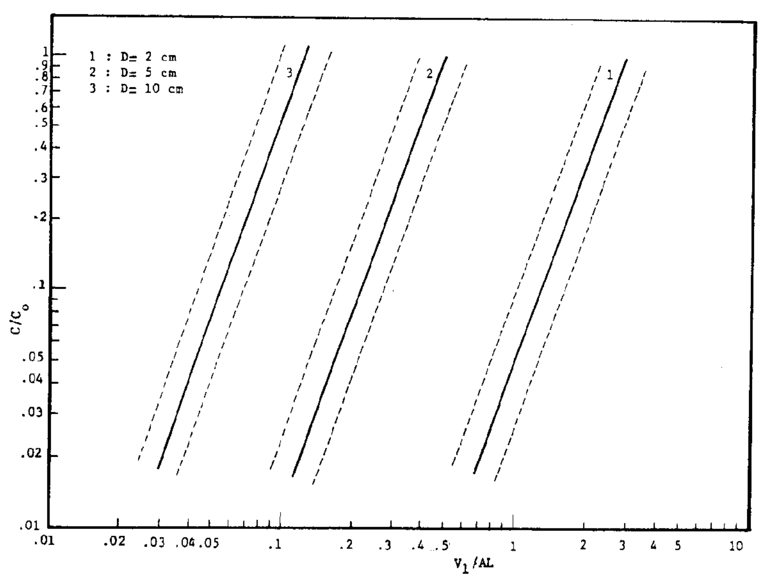


Fig. 4: Family of generated line

with a coefficient of correlation R = 0.9999. Substituting the value of b = 2.79 and the expression of the coefficient, a, in equation (1) into equation (2) gives the effluent boron concentration for any ion exchange column as:

$$C = 2.34 . 10^{-6} . Co. (AL)^{-0.043} (V_1)^{2.79} \quad (3)$$

Comparison of the calculated boron concentrations from equation (3) some of the measured values are presented in Table 4. Differences between measured and calculated values, and relative errors are also included in Table 4. Inpection of Table 4 shows that relative errors remain between 1.44 and 4.52 for most of the values, except the one for the column of 5 cm 1D.

Table 4: Comparison of effluent boron concentrations calculated from equation (3) with experimental results

Column diameter (cm)	Initial boron concentration Co (mg/1)	Effluent boron concentration (mg/1) mea-sured	calcu lated	different	Relative error in presemt
2	1600	669.25	652.70	+ 16.55	2.47
	500	137.57	140.53	- 2.96	2.15
	50	13.85	14.05	- 0.20	1.44
5	1600	580.80	607.09	- 26.29	4.52
	500	124.25	130.71	- 6.46	5.19
	50	12.87	13.07	- 0.20	1.55
10	1600	1046.20	1059.74	- 13.54	1.29
	500	253.80	246.82	+ 6.98	2.75
	50	17.00	17.31	0.31	1.82

Experimental

In order to investigate the effects of these variables, on the sorption capacity of Amberlite XE 243, a sample was taken from the effluent of borax and boric acid producing plant with a concentration of 1600 mg B/1 and was diluted with distilled water. Samples containing 500 and 50 mg B/1 were also prepared.

The above three samples were first treated with resin for different pH values to establish the optimum pH at which the maximum adsorption is attained. Maximum adsorption has been observed to take place at pH 8. Then the sorption of boron was observed at this pH by applying boron containing samples with flow rates of 1,2,3,4,6, 7, and 10 cm^3/min through the columns of 2.5 and 10 cm diameter. Initial boron concentrations were also 1600, 500 and 50 mg/1.

Boron concentrations were determined by the carminic acid and atomic absorption methods [9,10,11]. Experiments were conducted at room temperature. Water depth, above the top of the resin was kept constant and was equal to about 1 cm without pressure. Different volumes in increasing quantity were applied onto a fresh resin bed for each data point starting with initial concentration and flow rate of 3 cm^3/min, respectively.

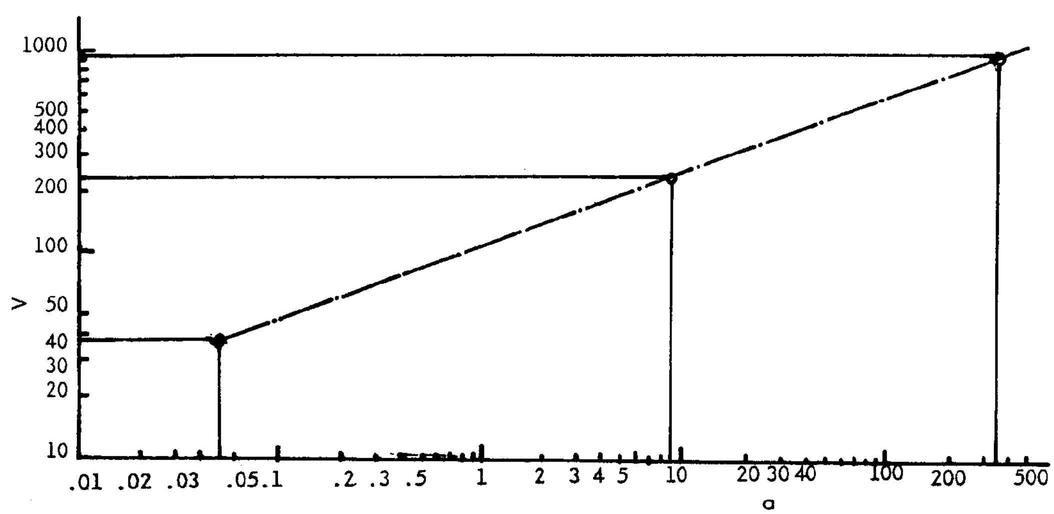
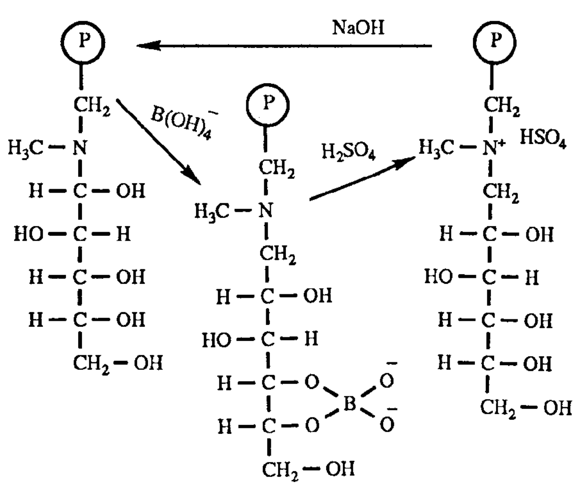


Fig. 5: Relation between a and AL

Regeneration

The exhausted beds were backwashed for 10 min at a column expansion of 100%. Conventionally the exhausted boron specific resin is regenerated with 10% sulphuric acid solution. Reageneration was done at a flow rate 10 cm^3/min. Since the amine group of the resin is neutralized during the acid regeneration to form the acid sulphate, hydrolysis of the amine acid sulphate during the subsequent exhaustion cycle results in a very acidic effluent. To avoid this, the resin is then converted back to the free amine form with 4% NaOH solution. The resin was then washed with distilled water. The following scheme expresses the loading and elution of the boron specific resin:



Conclusions

Laboraltory tests showed that boron can be removed from the wate waters of boric acid and borox plants by ion exchange. Then boron specific resin Amberlite EX 243 is very effective for boron removal from waste waters of mining inudstry, as expected. In the removal of boron by the method of ion exchange, various factors which are affecting, the sorption capacity of the resin and their efficiency are examined. The stronghest boron sorption capacity was observed at pH 8.

The boron concentration in the effluents at the optimum pH value were subjected to methematical and graphical analysis. Consequently, a multilinear equation relating the effluent boron concentration to resin volume and to effluent volume was presented. Developed equation can be used with a high degree of accuracy to predict the boron concentrations in the effluents.

Results of this work may form a basis for similar studies including different resins in ion exchange processes, which enable a practical design in boron removal from water and waste waters.

Nomenclature

The following symbols are used in this paper

a,b = coefficients in developed equation
A = crossectional area of the column (cm^2)
C = effluent boron concentration (mg/1)
C_o = initial boron concentration (mg/1)
D = column diameter (cm)
L = height of the resin in the column (cm)
R = correlation coefficient
t_1 = ion exchange time (s)
v = flow rate (cm^3/min)
V = resin volume (cm^3)
V_1 = total volume of water (cm^3)

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