

Use of type-II strong base anion exchange resins for ion exchange chromatographic separation of isotopes of boron

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Received 12 August 1996; accepted 26 May 1997

The optimum conditions for the regeneration of strong base anion exchange resins of type-I and type-II were determined for cost - effective separation of isotopes of boron by ion exchange chromatography. The possibility of using unspent alkali content of the effluent was also exploited. Removal of carbonate impurity from Rayon grade caustic lye (used as regenerant after dilution) and recycling of $\text{Ba}(\text{OH})_2$ was studied to avoid waste disposal problems. The determination of (i) ion exchange capacity of Duolite-162 resin for hydroxyl - chloride and hydroxyl - borate exchanges, (ii) isotopic exchange separation factor by batch method and (iii) effect of concentration of boric acid (in presence and absence of mannitol) on isotopic exchange separation factor to test the suitability of the type-II resin for this process are discussed.

Ion exchange resins find their applications both in research and industry including nuclear power stations. Because of the high neutron absorption cross-section of ^{10}B isotope, boron compounds enriched in this isotope are generally used for control rods of Fast Breeder Reactors (FBRs), neutron counters, neutron capture therapy of malignant tissues and treatment of melanotic cancers and brain tumours^{1,2}. For efficient control and to have a compact core size of fast reactors, it is required to use highly enriched boron in ^{10}B isotope (natural abundance of 18.8 at %). Ion exchange chromatography is an industrially viable process that could be used for the separation of stable isotopes of boron. After loading boric acid to the required band length, it is displaced with an acid to achieve the desired enrichment. In this process, involving anion exchange resins, hydroxyl form can only be employed due to its much higher affinity for the complexed borate anion compared with halide forms of the resin. Studies have been carried out earlier to enrich ^{10}B isotope of boron by ion exchange chromatography where a strong-base anion exchange resin of Type-I in hydroxyl form and glycerol³ or mannitol^{4,5} was used as a complexing reagent for boric acid. However, the industrial utility of this process, using a type-I

resin, gets limited by the higher cost of regeneration which is mainly due to required stoichiometric excess amounts of regenerant⁶. It is, therefore, necessary to significantly reduce the regeneration costs.

For regenerating strong base anion exchange resins, NaOH is generally used by diluting the commercially available Rayon grade caustic lye which contains small amounts of carbonate and chloride ions as impurities. Retention of chlorides is a common problem with strong base anion exchange resins^{7,8}. The present study was undertaken to: (a) investigate the effect of various factors that govern the regeneration of strong base anion exchange resin of type-II and are compared with type-I resin for selecting a suitable resin based on the ease of its regeneration and to know the extent of regeneration of the resin to hydroxyl form under suitable operational conditions; (b) study the removal of carbonate from the Rayon grade caustic lye and (c) carry out recycling of $\text{Ba}(\text{OH})_2$ to minimize the regeneration costs and to avoid other waste disposal related problems. Batch experiments were also carried out to determine (i) OH^- - Cl^- exchange capacity, (ii) OH^- borate exchange capacity, (iii) the effect of concentration of boric acid on the exchange capacity of the resin

Table 1—Characteristic properties of the candidate resins as determined experimentally using standard methods

Resin ^a	A	B	C	D	E	F	G
a	8.5	3.67	5.25	7.83	5.83	8.50	4.0
b	41	62.02	53.3	43.4	50.7	41.4	59
c	40	31	40	40	40	36	28
d	1.04	0.67	0.8	1.04	0.74	0.80	0.7
e	1.4	1.2	1.21	1.21	1.20	0.98	1.2
f	0.2	0.17	0.28	1.14	—	0.54	—
g	9.03	8.7	8.7	4.0	—	5.0	—
h	1.6	—	—	4.7	—5.0	—	—
i	29.2	30.2	14.4	39.6	12.3	17.0	115
j	1.103	1.243	1.18	1.228	1.22	1.175	1.18
k	1.196	1.076	1.07	1.114	0.66	1.2	—
l	—	—	0.64	1.114	0.66	1.2	—
m	—	—	0.62	1.046	0.552	0.94	—
n	—	—	—	1.09	0.64	0.93	—
o	0.53	0.32	—	0.55	—	0.52	—
p	350	320	290	320	280	310	—

a—Degree of cross-linking, %; b—Moisture content, %; c—Void volume, %; d—Breakthrough capacity^{<3>}, mEq/mL; e—Total capacity, mEq/mL; f—Selectivity coefficient, Cl^-/OH^- ; g—Variation in volume Cl^- to OH^- form, %; h—Variation in volume OH^- to borate form, %; i—Swelling, % Vol; j—Wet resin density, g/cc; k—Dry resin density, g/cc; l—Operating capacity Column method, mEq/mL; m—Operating capacity pH-titration method in water, mEq/mL; n—Operating capacity pH-titration method in 1.0M NaCl, mEq/mL; o—BSD, g/mL; p—Bead strength, g/bead.

^aA: Tulsion A-27 MP, B: Tulsion A-27 MP(S), C: Indion-810 (all type - I resins), D: Tulsion A-36 MP, E: Indion-820, F: Duolite-162 (all type-II resins), G: Tulsion A-351 (a gel type resin).

All the resins were styrene-divenyl benzene copolymer based macroporous beads (except for Tulsion A-351 a gel type resin).

^{<3>} At 5.8 mL/min flow rate for 1.81 cm internal diameter and 40 cm long column with 0.94 N NaOH.

for boric acid and (iv) isotopic exchange separation factor for ^{10}B - ^{11}B exchange at different concentrations of boric acid, in addition to isotopic exchange separation factor for ^{10}B - ^{11}B exchange at 0.1M boric acid in the presence of mannitol (a complexing reagent for boric acid) by using Type-II resins to access the suitability of a Type-II resin for the operation of the plant based on this process. The results of these experiments are discussed in the present paper.

Experimental Procedure

ANALAAR grade chemicals and demineralized water collected from CA-20 unit with conductivity of 1.5 $\mu\text{S}/\text{cm}$ was used throughout these experiments. After pretreatment in an usual manner, Tulsion A-27 MP (a type-I), Tulsion A-36 MP and Duolite-

162 (both type-II resins) were selected for the present study out of a large number of samples obtained from the various indigenous suppliers based on their optimum characteristic properties (determined experimentally and listed in Table 1). The experimental column consisted of a glass tube of 18.1 mm internal diameter and height of about 40 cm. Required volume of the regenerant solution was passed through the resin bed at a constant flow rate maintained within ± 0.2 percent with Miclins make PP-20 peristaltic pump. After rinsing with demineralized water to remove interstitial alkali, a known volume of standard HCl solution was passed through this column. The volume of entire effluent and washings collected was measured and titrated alkalimetrically to determine the total acid content. The percent regeneration was then

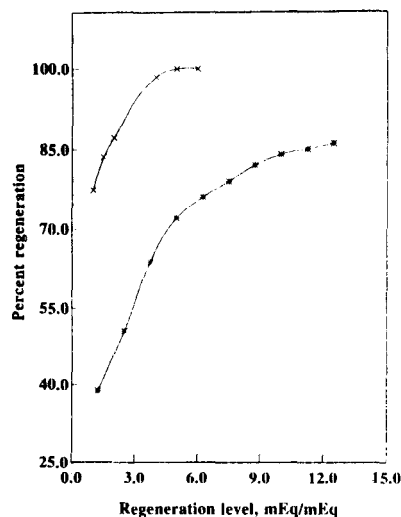


Fig. 1—Effect of regeneration level on percent regeneration of resins.

* * Tulsion A-27 MP, X-X Tulsion A-36 MP.

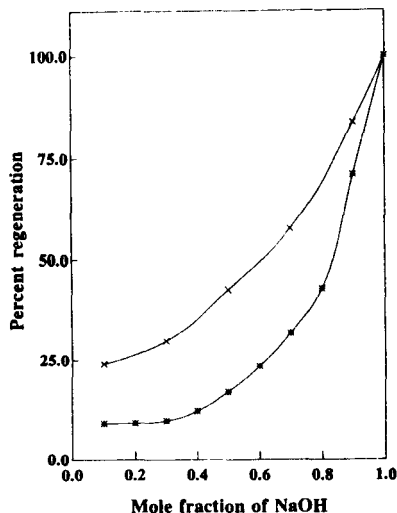


Fig. 2—Effect of mole fraction of NaOH in NaOH - NaCl mixtures on percent regeneration.

* * Tulsion A-27 MP, X-X Tulsion A-36 MP.

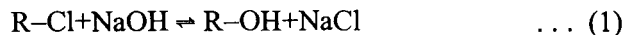
determined from the mEqs of HCl consumed. The total carbonate and hydroxide content of caustic lye was determined by acidimetric titrations and boric acid (alone or in its mixture with HCl) by alkalimetric titrations.¹⁰ For use in batch experiments, approx. 100 mL of resin slurry in chloride form was regenerated to hydroxyl form with 1.25N NaOH at 3 mEq/mEq regeneration level and 4.0 mL/min flow rate in the glass column. The isotopic analyses of boric acid for $^{10}\text{B}/^{11}\text{B}$ ratios were carried out by using a VG Micromass 30BK mass spectrometer having a thermal ionization source and a Daly detector.

To determine the isotopic exchange separation factor by batch method, a known quantity of the resin in hydroxyl form was taken in a stoppered bottle. To this, an aliquot of the boric acid solution (in absence or presence of the required amount of the complexing reagent, as the case may be) was added. The solution was allowed to equilibrate for 10 min. with intermittent stirring of the contents. The supernate was then discarded and a fresh aliquot of the solution was added. This procedure was repeated 20-25 times to ensure the completion of isotopic exchange reaction. The resin, thus converted to borate form, was then transferred to a small quartz column and the loaded boric acid was eluted with HCl. The effluent was isotopically analysed for $^{10}\text{B}/^{11}\text{B}$ ratios by treating a sample of boric acid with sodium carbonate to obtain 1:1

atom ratio of sodium to boron and loading on Rhenium filament. $^{10}\text{B}/^{11}\text{B}$ ratios were determined by measuring the peak heights at mass numbers 88 and 89 for sodium metaborate ion, containing ^{10}B and ^{11}B atoms respectively, produced by thermal ionization of Na_2BO_2 .

Results and Discussion

Regeneration studies—Regeneration of a strong base anion exchange resin from chloride (generally supplied) to hydroxyl form may be described as



where R is cationic resin network. Though, this reaction is quite fast, yet it is difficult to regenerate the resin completely to the hydroxyl form due to higher affinity of the resin for chloride ions as compared to hydroxyl ions. The regeneration of the resin from chloride form to hydroxyl form plays a vital role in this process (unlike in applications like deionization or demineralization etc.) due to the fact that the inventory of the boric acid in the column (and hence, the production capacity) depends upon the extent of regeneration of the resin and also lower values of isotopic exchange separation factors are obtained with resins in halide forms. The various factors which affect this regeneration process are—a) nature, concentration, purity and amount of regenerant

applied, b) flow rate, temperature and contact time, c) type of the functional group, grain size, degree of cross linking of the resin and composition of the exhausted resin bed⁹. Due to its availability at lower costs, NaOH is generally used as regenerant for strong base anion exchange resins. For operation of the plant, grain size of 20-50 US standard mesh is most suited to avoid the excessive pressure drops in the columns and room temperature operation is preferable. For the specific purpose of enrichment of ¹⁰B isotope of boron, the exhausted resin bed consist of resin only in the chloride form and the degree of cross-linking is about 8%. Hence, the factors which are important and are required to be studied are—regeneration level (milliequivalents of regenerant used per milliequivalent exchange capacity of the resin), concentration, purity and flow rate used.

It was observed that the percent regeneration of the resin was increased with increase in the regeneration level. The percent regeneration obtained for Tulsion A-36 MP resin was much higher compared to Tulsion A-27 MP as shown in Fig.1 which describes the plots of obtained percent regeneration versus regeneration levels at a constant flow rate (2.6 mL/min). This could be due to the difference in the functional groups of the two resins. However, at regeneration levels greater than 6.0 mEq/mEq resin capacity for Tulsion A-27 MP and 4.0 mEq/mEq resin capacity for Tulsion A-36 MP resin respectively, percent regeneration attained an almost steady value. This could be due to the fact that the selectivity coefficient of the resin for hydroxyl ions decreases with the increased fraction of resin in hydroxyl form.

At a fixed regeneration level of 2 mEq/mEq of ion exchange capacity and concentration at 1.25 N, the effect of flow rate on regeneration of the resin was studied by passing the required solution of NaOH through the resin bed. It was observed that for Tulsion A-27 MP resin, percent regeneration of the resin achieved was 58.16 ± 2.12 when the flow rate was increased from 0.25 to 3 mL/min and decreased drastically as the flow rate was increased further which could be due to the decrease in contact time. In the case of type-II resin, this effect was found to be less predominant compared to type-I resin as the percent regeneration achieved was 79.5 ± 1.7 when flow

rate was changed from 1.0 mL/min to 10.0 mL/min thus indicating thereby that a type-II resin could be regenerated at a higher flow rate compared to a type-I resin.

To study the effect of concentration, solutions of NaOH having different concentrations (0.5M to 2.0M) at a regeneration level of 2 mEq/mEq, were passed through the column containing chloride form of the resin and the percent regeneration obtained was 52.8 ± 1.25 . Beyond 1.25M NaOH, percent regeneration decreased gradually as the concentration of regenerant alkali was increased. This could be due to the decrease in the contact time of the regenerant with the resin. The effect was found to be more pronounced when the regeneration levels were low. Thus, it can be concluded that at low regeneration levels, lower concentrations of regenerant and flow rates should be utilized to provide longer contact times for getting higher regeneration. Further, it was observed that if the adequate contact time could be maintained, regenerant concentration had little effect on the regeneration of a type-II resin from chloride form to hydroxyl form.

Since excessive regeneration levels were required for complete regeneration, experiments were also carried out to see whether it was possible to utilize the unspent alkali content of the previous regenerant effluent so as to minimize the alkali consumption. To determine percent regeneration of the two resins in NaOH - NaCl mixtures in different mole fractions of NaOH, the required volumes of the mixture solutions, at a regeneration level of 2 mEq/mEq, were passed at a constant flow rate through the column and percent regenerations were determined. On plotting the data in Fig.2, it could be seen that the percent regeneration of the resin increased significantly only when the mole fraction of NaOH was greater than 0.8. The exchange isotherms obtained were similar to those reported¹² for Dowex resin. The maximum regenerations obtained were 72% and 83% of the ion exchange capacity respectively for the two resins when the mole fraction of NaOH was 0.9. Thus, presence of chloride ions in the regenerant plays an important role during the regeneration process and should be as low as possible so as to minimize the preferential absorption of Cl⁻ ions by the resin.

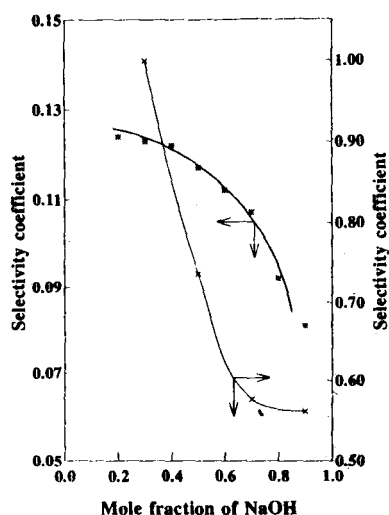


Fig.3—Selectivity coefficient for Tulsion A-27 MP and Tulsion A-36MP resins.

*—Tulsion A-27 MP, X-X Tulsion A-36 MP.

Experiments carried out for exploiting the unspent alkali content of the effluent indicated that by using first secondary regenerant with mole fraction of NaOH greater than 0.8 (approx 150 mEq of NaOH) and then fresh NaOH (264 mEq), 87% of the resin capacity for Tulsion A-27 MP resin (equivalent to regeneration at 400% regeneration level) could be converted to hydroxyl form at a flow rate of 2.0 mL/min for 100.0 mL resin bed volume whereas while using 264 mEq of fresh NaOH, under identical conditions, only 70% of the resin capacity could be regenerated to the hydroxyl form.

During regeneration, these resins undergo a change in volume by +10%. The swelling of the resin depends on the concentration of the external electrolyte solution apart from various other factors. Due to the higher ionic strength and low NaOH content of the secondary regenerant, the conversion of the resin was considerably slower. This reduced the osmotic shocks to the resin beads which could have otherwise led to their breakages. Further experiments indicated that while using secondary regenerant, there was no significant change in the percent regeneration of the resin even when washing of the exhausted resin bed was not carried out prior to the regeneration. This could be taken as an added advantage of using the secondary regenerant.

Selectivity coefficient studies—While aiming for the optimum conditions, systematic survey of

Table 2—Selectivity coefficient for OH^- — Cl^- exchange reaction for Tulsion A-36 MP resin at different regeneration levels and concentrations of NaOH

Regeneration levels mEq/mEq resin capacity	Selectivity Coefficient	Concentrations of NaOH/N,	Selectivity Coefficient
2.0	0.441	0.25	0.754
3.0	0.573	0.50	0.844
4.0	0.766	1.00	1.060
5.0	0.655	1.50	0.857
		2.0	0.676

distribution coefficients are a fundamental requirement for planning separation of elements by ion exchange chromatography¹³. The larger the amount of OH^- ions exchanged by the ion exchange resin from a solution containing Cl^- and OH^- ions, the higher is the value of the selectivity coefficient. K_d which is the ratio of the distribution coefficients of OH^- and Cl^- ions and this depends upon the nature of the resin used and increases with the increase in the degree of crosslinking¹⁴. In the present study, selectivity coefficients of Cl^- — OH^- exchange for the resins studied were determined from the exchange isotherms¹⁵ of NaOH—NaCl at various mole fractions and a total ionic strength of 1.25 M. The values of selectivity coefficients for Tulsion A-27 MP varied from 0.124 to 0.081 over the 0.2-0.9 mole fraction range whereas for Tulsion A-36 MP, it decreased from 1.0 to 0.562 as the mole fraction of NaOH was increased from 0.3 to 0.9 as is evident from Fig.3. The selectivity coefficients of Tulsion A-36 MP resin were higher for Cl^- to OH^- exchange compared to Tulsion A-27 MP resin due to the differences in their functional groups. All the above mentioned experiments confirmed that a Type-II resin could be regenerated easily. Hence, further experiments were carried out only by using a Type-II resin.

Using batch equilibration method, the effect of regeneration level (in the range 2.0-5.0 mEq/mEq resin capacity) on the selectivity coefficient for the Cl^- — OH^- exchange reaction was determined. In a similar way, the effect of concentration of regenerant NaOH on the selectivity coefficient was also determined. The obtained data are presented

Table 3—Height equivalent to a theoretical plate (HETP) for OH[−]—Cl[−] exchange reaction for Tulsion A-36 MP resin at different flow rates and concentrations of NaOH.

Flow rate mL/min	HETP mm	Concentration of NaOH, N	HETP mm
1.43	1.54	0.25	1.60
2.15	2.18	0.75	1.41
3.71	3.95	1.00	1.75
4.40	4.08		
7.15	6.80		
17.5	10.12		

in Table 2. From the table, it could be observed that with increase in regeneration level, the value of selectivity coefficient increased when regeneration level was increased from 2.0–4.0 mEq/mEq of resin capacity and decreased thereafter for Tulsion A-36 MP resin. It could also be seen that selectivity coefficient values increased when the concentration of NaOH was increased from 0.25N to 1.0N and decreased henceforth from which it was inferred that a regeneration level of 3.0–4.0 mEq/mEq resin capacity and 1.0N concentration are the optimum conditions for regeneration of a type-II resin. The ion exchange reaction for the regeneration process, as mentioned in Eq.(1) when carried out in closed system goes to equilibrium conditions due to the reversible nature of ion exchange reactions. The equilibrium concentration of the ions taking part in the exchange reaction viz, OH[−] and Cl[−] is not identical and depends upon their initial concentration and the value of relative affinity of these ions to the ion exchange resin. The apparent equilibrium constant K_x , for this reaction is given by

$$K_x = \frac{[R-OH] \cdot [Cl^-]}{[R-Cl] \cdot [OH^-]} = K_d \text{ for monovalent ion}$$

exchange reactions.

The thermodynamic equilibrium constant for this reaction is,

$$K_s = \frac{[RO^-] \cdot [Cl^-]}{[R-Cl] \cdot [OH^-]} = K_x \frac{\gamma_{R-OH} \cdot f_{Cl^-}}{\gamma_{R-Cl} \cdot f_{OH^-}}$$

where (γ) denotes the activity, γ 's are the activity coefficient of the ions in the resin phase and f 's are their activity coefficient in the solution phase. At

low concentration of NaOH, the ratio of activity coefficient in the resin phase may be regarded as constant and thus with increase in concentration of NaOH, initially the ratio of activity coefficient of two ions in the solution phase increases which leads to the increased value of selectivity coefficient whereas at higher concentration, this ratio decreases and hence, lower values of K_d are obtained. Thus, the reversal of the trend for variation in the values of selectivity coefficient with increase in concentration of NaOH could be due to change in activity coefficient and the volume of the hydration shell of the ion or change in the ratio of volume of solution taken to the weight (volume) of the resin used while studying the effect of regeneration level.

Since, HETP (height equivalent to a theoretical plate) is a second important parameter of basic importance to be considered during chromatographic separations¹⁶, the effect of concentration and flow rate on HETP were also studied. The values of HETP determined¹⁷ at different concentrations of NaOH and at different flow rates are listed in Table 3. From the table, it was observed that HETP decreased as the flow rate was increased whereas the concentration of regenerant in the range (0.25N–1.0N) had no significant effect. Hence, for better regeneration, the optimum concentration of the regenerant should be passed through the column at lower flow rates to achieve the minimum value of HETP and, therefore, maximum number of theoretical plates in the column. As similar results were obtained for Duolite-162 resin, the data are not reported here.

Studies on carbonate removal from regenerant alkali—The carbonate ions present as an impurity in caustic lye form a band at the top portion of the resin column during the regeneration process due to their preferential absorption from the dilute solutions. During displacement, the eluted carbonate reacts with HCl evolving CO₂ gas which disturbs the borate band enriched in the desired isotope. Hence, it was necessary to reduce carbonate impurity from the regenerant alkali. Two different methods were employed to reduce its carbonate content. These were (i) use of strong base anion exchanger and (ii) BaCO₃ precipitation. As strong base anion exchange resins have higher affinity for weak acid anions, in the first method,

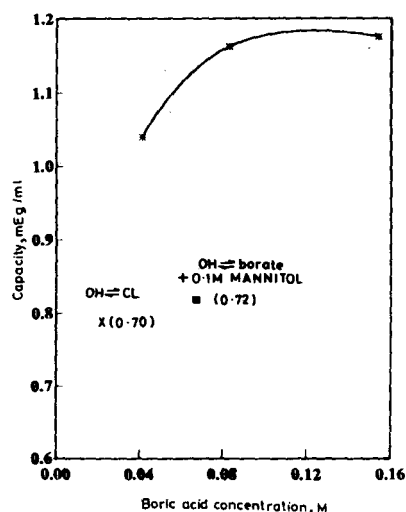


Fig.4—Effect of concentration of boric acid on exchange capacity of Duolite-162 for boric acid

* * boric acid

the regenerant solution was passed through a resin column containing strong base anion exchanger of type I (Tulsion A-27 MP) in the hydroxyl form. The effluent was collected in a polythene bottle under CO₂ free atmosphere and was analysed for carbonate content, which was found to be below the detection limit of titrimetric analysis as long as there was no leakage of carbonate ions from the hydroxyl form of the resin (which was indicated by the change in colour of the resin).

In the second method, stoichiometric excess amount of Ba(OH)₂ solution was added to the aliquot of lye solution. After allowing sufficient time for precipitation, the solution was filtered and the carbonate content of the filtrate was determined by titrimetric and conductimetric methods and was found to be below the detection limits.

Although, both the above mentioned methods seem to be equally effective in reducing the carbonate content, the use of BaCO₃ precipitation is limited due to the observation of a cloud formed by the reaction of atmospheric CO₂ with the excess of Ba(OH)₂. The optimum conditions may, however, be obtained by first reducing the carbonate content of the lye by precipitation as BaCO₃ using sub-stoichiometric amounts of Ba(OH)₂ so as to avoid the cloud formation and excessive loads on the resin bed used for regenerant purification. The supernate from the above process may then be

further purified by using type-I strong base anion exchange resin which would also help in ensuring lower chloride content in the regenerant (a requirement based on the observed effect of chloride ions on regeneration).

Recycling of barium hydroxide—The precipitates of BaCO₃ formed in the above treatment cannot be directly disposed due to their toxic nature. To avoid this waste disposal related problems, barium carbonate precipitates were filtered and neutralized with concentrated HCl. The BaCl₂ solution so produced was fed to an anion exchange resin column in hydroxyl form. Ba(OH)₂ produced as a result of Cl⁻-OH⁻ exchange process was reused to precipitate the carbonate impurity present in the regenerant. CO₂ gas produced was absorbed in 1g/mL NaOH solution leading to precipitation of the formed Na₂CO₃ which posed no waste disposal problems.

To compare OH⁻ - borate exchange capacity of the resin with OH⁻-Cl⁻ exchange capacity, the capacity of the resin for two exchange reactions were determined by taking the resin from same regenerated lot. OH⁻-Cl⁻ exchange capacity of the resin was determined by equilibrating 10.0 mL aliquots of standard HCl solution (0.089N) 25 times with hydroxyl form of the resin and determining the amount of the acid consumed.

OH⁻ borate exchange capacity of the resin for boric acid (in presence or absence of mannitol) was also determined in a similar way by analysing boric acid alkalimetrically after the addition of mannitol. The capacity of the resin for OH⁻-Cl⁻ exchange was found to be 0.704 mEq/mL. For boric acid solution containing 0.1 M mannitol, it was found to be 0.720 mEq/mL. This shows that there was no significant difference in resin capacity when boric acid solution containing mannitol was equilibrated as compared to that observed for OH⁻-Cl⁻ exchange. Similar results were obtained when the resin was partially regenerated at lower regeneration levels thus confirming that boron inventory in the column is reduced when the resin bed was regenerated to a lesser extent.

In the absence of mannitol, however, the capacity of the resin for boric acid increased and reached a steady value as shown in Fig.4. This could be due to the exchange of polyborate ions

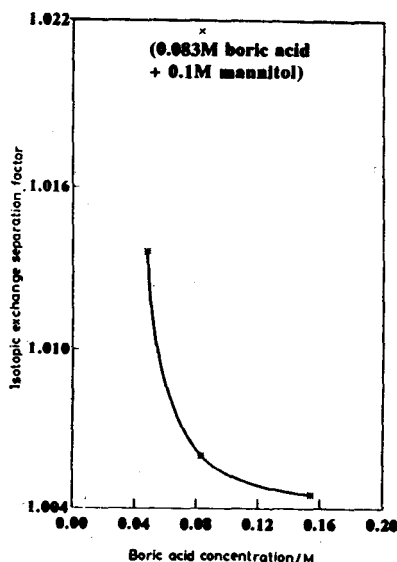


Fig.5(a)—Effect of concentration of boric acid (in presence and absence of mannitol) on isotopic exchange separation factor for Duolite-162 resin.

* * boric acid

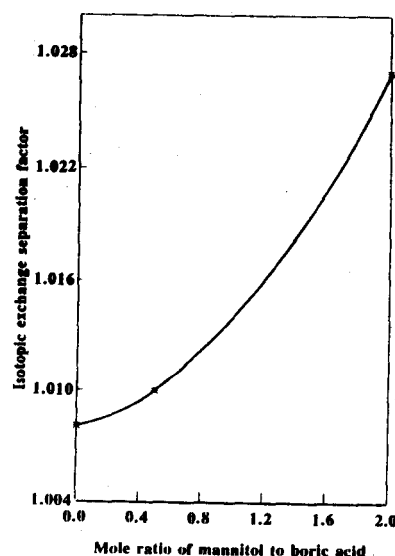


Fig.5(b)—Effect of mannitol to boric acid mole ratio on isotopic exchange separation factor using Tulsion A-36MP resin.

with hydroxyl form of the resin. Thus, it could be inferred that in presence of mannitol, the capacity of the resin remained almost same due to the exchange of mononuclear mannitol-borate complex anion by reacting with polyborate ions¹⁸ present in boric acid solutions at higher concentrations.

Though, the capacity of the resin could be calculated from the volume basis to dry weight basis using the data in Table 1 and the equation $Q_v = (1 - \epsilon_i) \{ (100 - S) / 100 \}$ where Q_v is volume capacity of the column, Q_m is the weight capacity, ϵ_i is relative interstitial volume, p is the density of the swollen resin and $\langle I \rangle S \langle D \rangle$ is water content (in weight %) of the resin, the volume basis is followed specifically as the entire data obtained in this study is required for the operation of the plant (being setup shortly).

From the data obtained for isotopic ratios, the mole fractions of ^{10}B in the samples were calculated from the equation $X = R / (1 + R)$ where R is the abundance ratio i.e. $^{10}\text{B}/^{11}\text{B}$ for a particular sample. The values of isotopic exchange separation factor, K , were then determined from the equation⁵

$$K = \frac{(X_i) \cdot (1 - X_s)}{(1 - X_r) \cdot (X_s)} \quad \dots (3)$$

where X_r is the mole fraction of ^{10}B in the resin phase and X_s in the solution phase. The values of isotopic exchange separation factor obtained by equilibrating the Duolite - 162 resin in the hydroxyl form at different concentrations of boric acid are plotted in Fig.5(a). From this figure, it could be observed that as the concentration of boric acid was increased, the value of isotopic exchange separation factor decreased. This could be due to the exchange of polynuclear complexes of boric acid called polyborates with hydroxyl form of the resin. Using Tulsion A-36 MP resin, batch experiments were also carried out to determine the effect of concentration of mannitol in 0.1 M boric acid on separation factor and the results are presented in Fig.5(b). It was found that in this case also there was increase in the value of isotopic exchange separation factor as mannitol concentration was increased from 0.0-0.2M. Thus, from the present study it could be concluded that with the increase in the concentration of boric acid, the exchange capacity increases and separation factor value decreases which could be due to the exchange of polyborate anions with hydroxyl form of the resin. The polyborate formation was significantly reduced by the addition of mannitol to boric acid. The value of isotopic exchange separation factor was increased considerably with

addition of 0.1M mannitol as complexing reagent to 0.1 M boric acid. This increase in the value of isotopic exchange separation factor was similar to the one obtained for type-I resin from which it could be concluded that in addition to their better regeneration characteristics, the Type-II resins studied were also as effective as Type-I resins for the purpose of separation of isotopes of boron by ion exchange chromatography.

Acknowledgements

The authors are grateful to Dr. Placid Rodriguez, Director, IGCAR and Shri S.B. Bhoje, Director, Reactor Group for their keen interest in this work. Thanks are also due to Dr. G. Periaswami, Head, Materials Chemistry Division, Chemical Group, IGCAR for isotopic analyses.

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