

# Comparative Study of Indion-AGR and Duolite A-638 Anion Exchange Resins by Application of $^{131}\text{I}$ and $^{82}\text{Br}$ as a Tracer Isotopes

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**Abstract** The present study deals with modeling of ion-isotopic exchange reaction kinetics by application of radioactive tracer isotopes  $^{82}\text{Br}$  and  $^{131}\text{I}$ . The bromide and iodide ion-isotopic exchange reactions were carried out by using weak base anion exchange resins Indion-AGR and Duolite A-638. It was observed that for both the resins, reaction rate decreases with rise in temperature and increases with increase in ionic concentration. The study was extended further for characterization of these resins based on their performance under different operational parameters. It was observed that the percentage/amount of ions exchanged and distribution coefficient values calculated for Duolite A-638 was higher than Indion-AGR resins under identical operational parameters, indicating superior performance of Duolite A-638 over Indion-AGR resins.

**Keywords** Indion-AGR, Duolite A-638, Tracer Applications, Reaction Kinetics, Ion-Isotopic Exchange Reactions,  $^{131}\text{I}$ ,  $^{82}\text{Br}$ , Distribution Coefficient, Reaction Rate

## 1. Introduction

Radioisotopes find applications in several fields of which industrial applications constitute a major portion with respect to the quantum of activity used and the economic benefits accrued. Industrial applications of radioisotopes can be mainly categorized into two. The first one being the use of radiation from sealed sources of radioisotopes or from electron beam accelerators for industrial processing, non-destructive testing. The second major group of applications is the use of radiotracers in inventory control, study of process parameters, trouble shooting in industrial systems, flow measurements, leakage studies etc. The economic benefits that may be derived from the use of the radioisotope technology are great, a fact that is recognized by the governments of developing countries. Though radioisotopes have been applied to the solution of problems in industry for over 50 years, research and development of the technology continues unabated. There are two main reasons for the continuing interest. Firstly, it is industry driven. Because of their unique properties, radioactive isotopes can be used to obtain information about plants and processes that cannot be obtained in any other way. Often, the information is obtained with the plant on-stream and

without disrupting the process in any way. This can lead to substantial economic benefits, from shutdown avoidance to process optimization. Secondly, the methodology is derived from many fields of science and technology including radioisotope production, radiation detection, data acquisition, treatment and analysis, and mathematical modeling.

The fundamental principle in radiochemical investigations is that the chemical properties of a radioisotope of an element are almost the same as those of the other stable/radioactive isotopes of the element. When radioisotope is present in a chemical form identical to that of the bulk of the element in a chemical process, then any reaction the element undergoes can be directly traced by monitoring the radioisotope. Radiochemical work involves two main steps first is the sampling of chemical species to be studied and second is quantitative determination of the radiation emitted by the radioisotope in the sample[1]. In radiotracer study, a short lived radioisotope in a physico-chemical form similar to that of the process material is used to trace the material under study. The radioisotopes in suitable physical and chemical forms are introduced in systems under study. By monitoring the radioactivity both continuously or after sampling (depending on the nature of study), the movement, adsorption, retention etc. of the tracer and in turn, of the bulk matter under investigation, can be followed. The tracer concentration recorded at various locations also helps to draw information about the dynamic behavior of the system under study. The radioisotopes preferred for such studies are gamma emitters having half-life compatible with the

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duration of studies. The strength of radioactivity used varies depending on the nature of application. Applications of radiotracers in chemical research cover the studies of reaction mechanism, kinetics, exchange processes and analytical applications such as radiometric titrations, solubility product estimation, isotope dilution analysis and autoradiography. Radioisotope tracers offer several advantages such as high detection sensitivity, capability of in-situ detection, limited memory effects and physic-chemical compatibility with the material under study. The radioisotopes have proved as a tool to study many problems in chemical, biological and medicinal fields. Radiotracers have helped in identification of leaks in buried pipelines and dams. Process parameters such as mixing efficiency, residence time, flow rate, material inventory and silt movement in harbours are studied using radioisotopes[1]. The efficiency of several devices in a wastewater treatment plant (primary and secondary clarifiers, aeration tank) is investigated by means of radiotracers[2].

Considering the above wide use of radioactive isotopes in various industrial and technical applications, in the present investigation, they are applied to assess the performance of industrial grade anion exchange resins Indion-AGR and Duolite A-638 under different operational parameters like temperature and ionic concentrations. It is expected that the tracer technique used here can also be used for characterization of other organic ion exchange resins which are synthesized for their specific technical applications[3-8]. The present technique can also be extended further to standardize the operational parameters so as to bring about the most efficient performance of those resins in their specific industrial applications.

## 2. Experimental

### 2.1. Conditioning of Ion Exchange Resins

Ion exchange resin Indion-AGR (by Ion Exchange India Ltd., Mumbai) and Duolite A-638 (by Auctel Product Ltd., Mumbai) are weakly basic anion exchange resin in chloride form having tertiary ammonium functional group. Details regarding the properties of the resins used are given in Table 1. These resins were converted separately into iodide / bromide form by treatment with 10% KI / KBr solution in a conditioning column which is adjusted at the flow rate as 1 mL / min. The resins were then washed with double distilled water, until the washings were free from iodide/bromide ions as tested by  $\text{AgNO}_3$  solution. These resins in bromide and iodide form were then dried separately over  $\text{P}_2\text{O}_5$  in desiccators at room temperature.

### 2.2. Radioactive Tracer Isotopes

The radioisotope  $^{131}\text{I}$  and  $^{82}\text{Br}$  used in the present experimental work was obtained from Board of Radiation and Isotope Technology (BRIT), Mumbai. Details regarding the isotopes used in the present experimental work are given

in Table 2.

**Table 1.** Properties of ion exchange resins

Ion exchange resin	Matrix	Moisture content (%)	Maximum operating temperature ( $^{\circ}\text{C}$ )	Total exchange capacity (meq./mL)
Indion-AGR	Crosslinked Polystyrene	51	60	1.3
Duolite A-638	Crosslinked Polystyrene	<2.0	60	4.0

**Table 2.** Properties of  $^{131}\text{I}$  and  $^{82}\text{Br}$  tracer isotopes[9]

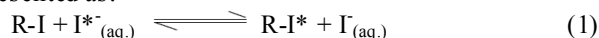
Isotopes	Half-life	Radioactivity / mCi	$\gamma$ -energy / MeV	Chemical form	Physical form
$^{131}\text{I}$	8.04 d	5	0.36	Iodide*	Aqueous
$^{82}\text{Br}$	36 h	5	0.55	Bromide**	Aqueous

\* Sodium iodide in dilute sodium sulphite.

\*\* Ammonium bromide in dilute ammonium hydroxide.

### 2.3. Study on Kinetics of Iodide Ion-Isotopic Exchange Reaction

In a stoppered bottle 250 mL ( $V$ ) of 0.001 M iodide ion solution was labeled with diluted  $^{131}\text{I}$  radioactive solution using a micro syringe, such that 1.0 mL of labeled solution has a radioactivity of around 15,000 cpm (counts per minute) when measured with  $\gamma$ -ray spectrometer having NaI (TI) scintillation detector. Since only about 50–100  $\mu\text{L}$  of the radioactive iodide ion solution was required for labeling the solution, its concentration will remain unchanged, which was further confirmed by potentiometer titration against  $\text{AgNO}_3$  solution. The above labeled solution of known initial activity ( $A_i$ ) was kept in a thermostat adjusted to  $30.0^{\circ}\text{C}$ . The swelled and conditioned dry ion exchange resins in iodide form weighing exactly 1.000 g ( $m$ ) were transferred quickly into this labeled solution which was vigorously stirred by using mechanical stirrer and the activity in cpm of 1.0 mL of solution was measured. The solution was transferred back to the same bottle containing labeled solution after measuring activity. The iodide ion-isotopic exchange reaction can be represented as:



Here R-I represents ion exchange resin in iodide form;  $\text{I}^{*}_{(\text{aq})}$  represents aqueous iodide ion solution labeled with  $^{131}\text{I}$  radiotracer isotope.

The activity of solution was measured at a fixed interval of every 2.0 min. The final activity ( $A_f$ ) of the solution was also measured after 3h which was sufficient time to attain the equilibrium[10-24]. The activity measured at various time intervals was corrected for background counts.

Similar experiments were carried out by equilibrating separately 1.000 g of ion exchange resin in iodide form with labeled iodide ion solution of four different concentrations ranging up to 0.004 M at a constant temperature of  $30.0^{\circ}\text{C}$ . The same experimental sets were repeated for higher

temperatures up to 45.0°C.

## 2.4. Study on Kinetics of Bromide Ion-Isotopic Exchange Reaction

The experiment was also performed to study the kinetics of bromide ion- isotopic exchange reaction by equilibrating 1.000 g of ion exchange resin in bromide form with labeled bromide ion solution in the same concentration and temperature range as above. The labeling of bromide ion solution was done by using  $^{82}\text{Br}$  as a radioactive tracer isotope for which the same procedure as explained above was followed. The bromide ion-isotopic exchange reaction can be represented as:



Here R-Br represents ion exchange resin in bromide form;  $\text{Br}^{*-}(\text{aq.})$  represents aqueous bromide ion solution labeled with  $^{82}\text{Br}$  radiotracer isotope.

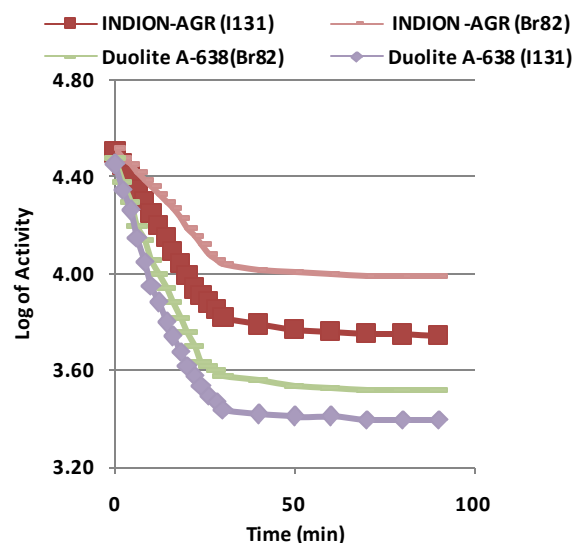
## 3. Results and Discussion

### 3.1. Comparative Study of Ion-Isotopic Exchange Reactions

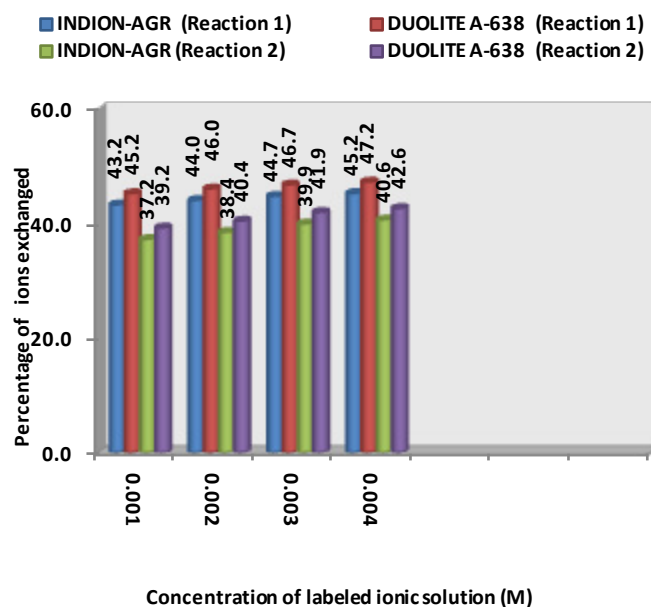
In the present investigation it was observed that due to the rapid ion-isotopic exchange reaction taking place, the activity of solution decreases rapidly initially, then due to the slow exchange the activity of the solution decreases slowly and finally remains nearly constant. Preliminary studies show that the above exchange reactions are of first order[25, 26]. Therefore logarithm of activity when plotted against time gives a composite curve in which the activity initially decreases sharply and thereafter very slowly giving nearly straight line (Figure 1), evidently rapid and slow ion-isotopic exchange reactions were occurring simultaneously[10-24]. Now the straight line was extrapolated back to zero time. The extrapolated portion represents the contribution of slow process to the total activity which now includes rapid process also. The activity due to slow process was subtracted from the total activity at various time intervals. The difference gives the activity due to rapid process only. From the activity exchanged due to rapid process at various time intervals, the specific reaction rates ( $k$ ) of rapid ion-isotopic exchange reaction were calculated. The amount of iodide / bromide ions exchanged (mmol) on the resin were obtained from the initial and final activity of solution and the amount of exchangeable ions in 250 mL of solution. From the amount of ions exchanged on the resin (mmol) and the specific reaction rates ( $\text{min}^{-1}$ ), the initial rate of ion exchanged ( $\text{mmol}/\text{min}$ ) was calculated.

Because of larger solvated size of bromide ions (310 pm) as compared to that of iodide ions (300 pm), it was observed that the exchange of bromide ions occurs at the slower rate than that of iodide ions[27]. Hence under identical experimental conditions, the values of specific reaction rate ( $\text{min}^{-1}$ ), amount of ion exchanged (mmol) and initial rate of ion exchange ( $\text{mmol}/\text{min}$ ) are calculated to be lower for

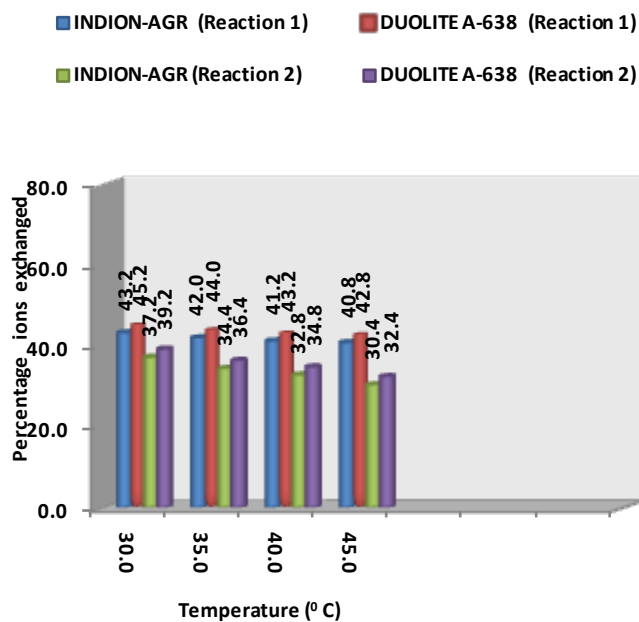
bromide ion-isotopic exchange reaction than that for iodide ion-isotopic exchange reaction as summarized in Tables 3 and 4. For both bromide and iodide ion-isotopic exchange reactions, under identical experimental conditions, the values of specific reaction rate increases with increase in concentration of ionic solution from 0.001M to 0.004M (Table 3). However, with rise in temperature from 30.0°C to 45.0°C, the specific reaction rate was observed to decrease (Table 4). From the results, it appears that iodide ions exchange at the faster rate as compared to that of bromide ions which was related to the extent of solvation (Tables 3 and 4).



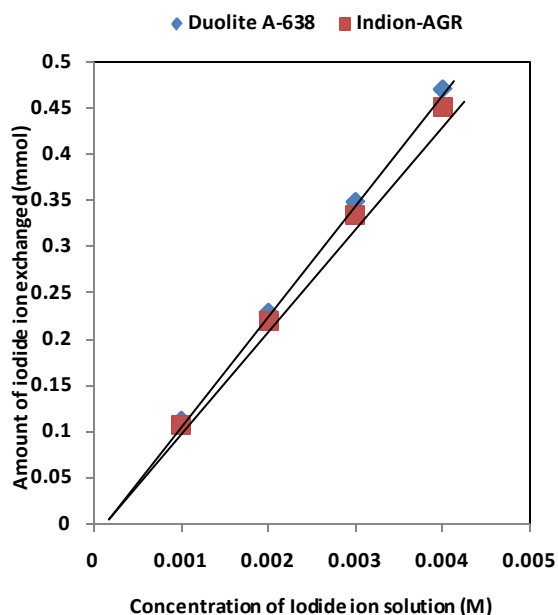
**Figure 1.** Kinetics of Ion-Isotopic Exchange Reactions Amount of ion exchange resin = 1.000 g, Concentration of labeled exchangeable ionic solution = 0.001M, Volume of labeled ionic solution = 250 mL, Temperature = 30.0°C



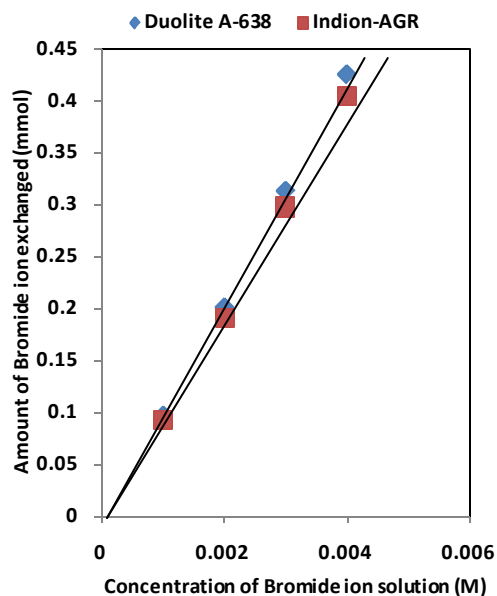
**Figure 2.** Variation in Percentage Ions Exchanged with Concentration of Labeled Ionic Solution Amount of ion exchange resin = 1.000 g, Volume of labeled ionic solution = 250 mL, Temperature = 30.0°C



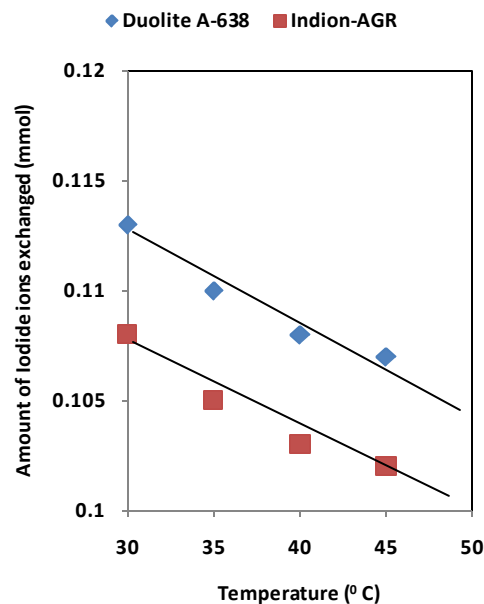
**Figure 3.** Variation in Percentage Ions Exchanged with Temperature of Labeled Ionic Solution Amount of ion exchange resin = 1.000 g, Concentration of labeled exchangeable ionic solution = 0.001M, Volume of labeled ionic solution = 250 mL, Amount of exchangeable ions in 250 mL labeled solution = 0.250 mmol



**Figure 4.** Correlation between concentrations of iodide ion solution and amount of iodide ion exchanged Amount of ion exchange resin = 1.000 g, Volume of labeled ionic solution = 250 mL, Temperature = 30.0°C Correlation coefficient (r) for Indion-AGR = 1.0000 Correlation coefficient (r) for Duolite A-638 = 1.0000

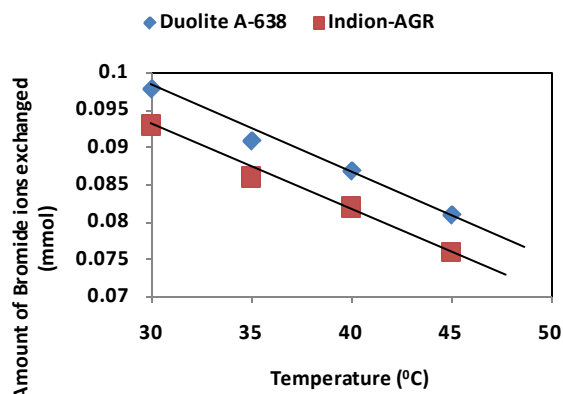


**Figure 5.** Correlation between concentrations of bromide ion solution and amount of bromide ion exchanged Amount of ion exchange resin = 1.000 g, Volume of labeled ionic solution = 250 mL, Temperature = 30.0°C Correlation coefficient (r) for Indion-AGR = 0.9998 Correlation coefficient (r) for Duolite A-638 = 0.9998



**Figure 6.** Correlation between Temperatures of exchanging medium and amount of iodide ion exchanged Amount of ion exchange resin = 1.000 g, Concentration of labeled exchangeable ionic solution = 0.001M, Volume of labeled ionic solution = 250 mL, Amount of exchangeable ions in 250 mL labeled solution = 0.250 mmol Correlation coefficient (r) for Indion-AGR = -0.9759 Correlation coefficient (r) for Duolite A-638 = -0.9759





**Figure 7.** Correlation between Temperatures of exchanging medium and amount of bromide ion exchanged Amount of ion exchange resin = 1.000 g, Concentration of labeled exchangeable ionic solution = 0.001M, Volume of labeled ionic solution = 250 mL, Amount of exchangeable ions in 250 mL labeled solution = 0.250 mmol Correlation coefficient (r) for Indion-AGR = -0.9951 Correlation coefficient (r) for Duolite A-638 = -0.9951

From the knowledge of  $A_i$ ,  $A_f$ , volume of the exchangeable ionic solution ( $V$ ) and mass of ion exchange resin ( $m$ ), the  $K_d$  value was calculated by the equation

$$K_d = [(A_i - A_f) / A_f] \times V / m \quad (3)$$

Heumann *et al.*[28] in the study of chloride distribution coefficient on strongly basic anion exchange resin observed that the selectivity coefficient between halide ions increased at higher electrolyte concentrations. Adachi *et al.*[29] observed that the swelling pressure of the resin decreased at higher solute concentrations resulting in larger  $K_d$  values. The temperature dependence of  $K_d$  values on cation exchange resin was studied by Shuji *et al.*[30]; were they observed that the values of  $K_d$  increased with fall in temperature. The present experimental results also indicates that the  $K_d$  values for bromide and iodide ions increases with increase in ionic concentration of the external solution, however with rise in temperature the  $K_d$  values were found to decrease. It was also observed that the  $K_d$  values for iodide ion-isotopic reaction were calculated to be higher than that for bromide ion-isotopic reaction (Tables 3 and 4).

### 3.2. Comparative Study of Anion Exchange Resins

From the Table 3, it is observed that for iodide ion-isotopic exchange reaction by using Duolite A-638 resin, the values of specific reaction rate (min<sup>-1</sup>), amount of iodide ion exchanged (mmol), initial rate of iodide ion exchange (mmol/min) and log  $K_d$  were 0.120, 0.113, 0.014 and 6.7 respectively, which was higher than 0.103, 0.108, 0.011 and 6.1 respectively as that obtained by using Indion-AGR resins under identical experimental conditions of 30.00°C, 1.000 g of ion exchange resins and 0.001 M labeled iodide ion solution. The identical trend was observed for the two resins during bromide ion-isotopic exchange reaction.

From Table 3, it is observed that using Duolite A-638 resins, at a constant temperature of 30.0 °C, as the concentration of labeled iodide ion solution increases 0.001

M to 0.004 M, the percentage of iodide ions exchanged increases from 45.2 % to 47.2%. While using Indion-AGR resins under identical experimental conditions the percentage of iodide ions exchanged increases from 43.2 % to 45.2 %. Similarly in case of bromide ion-isotopic exchange reaction, the percentage of bromide ions exchanged increases from 39.2% to 42.6% using Duolite A-638 resin, while for Indion-AGR resin it increases from 37.2 % to 40.6 %. The effect of ionic concentration on percentage of ions exchanged is graphically represented in Figure 2.

From Table 4, it is observed that using Duolite A-638 resins, for 0.001 M labeled iodide ion solution, as the temperature increases 30.0°C to 45.0°C, the percentage of iodide ions exchanged decreases from 45.2 % to 42.8 %. While using Indion-AGR resins under identical experimental conditions the percentage of iodide ions exchanged decreases from 43.2 % to 40.8 %. Similarly in case of bromide ion-isotopic exchange reaction, the percentage of bromide ions exchanged decreases from 39.2 % to 32.4 % using Duolite A-638 resin, while for Indion-AGR resin it decreases from 37.2 % to 30.4 %. The effect of temperature on percentage of ions exchanged is graphically represented in Figure 3.

The overall results indicate that under identical experimental conditions, as compared to Indion-AGR resins, Duolite A-638 resins shows higher percentage of ions exchanged. Thus Duolite A-638 resins show superior performance than Indion-AGR resins under identical operational parameters.

### 3.3. Statistical Correlations

The results of present investigation show a strong positive linear co-relationship between amount of ions exchanged and concentration of ionic solution (Figures 4, 5). In case of iodide ion-isotopic exchange using Duolite A-638 and Indion-AGR resins, the values of correlation coefficient (r) was calculated as 1.0000, while for bromide ion-isotopic exchange the values of r was calculated as 0.9998 for both the resins.

There also exist a strong negative co-relationship between amount of ions exchanged and temperature of exchanging medium (Figures 6, 7). In case of iodide ion-isotopic exchange reactions the values of r calculated for Duolite A-638 and Indion-AGR resins was -0.9759. Similarly in case of bromide ion-isotopic exchange reactions the r values calculated was -0.9951 for both the resins.

## 4. Conclusions

The experimental work carried out in the present investigation will help to standardize the operational process parameters so as to improve the performance of selected ion exchange resins. The radioactive tracer technique used here can also be applied for characterization of different nuclear as well as non-nuclear grade ion exchange resins.

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## REFERENCES

- [1] Sood, D.D., Reddy, A.V.R., and Ramamoorthy, N., 2004, Applications of Radioisotopes In Physico-Chemical Investigations., in Fundamentals of Radiochemistry, Indian Association of Nuclear Chemists and Allied Scientists (IANCAS), 253-263.
- [2] Radiotracer Applications in Industry- A Guidebook, 2004, Safety Reports Series No. 423, International Atomic Energy Agency (IAEA) Vienna.
- [3] Zhu, L., Liu, Y., and Chen, J., 2009, Synthesis of *N*-Methylimidazolium Functionalized Strongly Basic Anion Exchange Resins for Adsorption of Cr(VI)., *Ind. Eng. Chem. Res.*, 48(7), 3261-3267.
- [4] Korshak, V.V., Rogozhin, S.V., Davankov, V.A., and Vyrbanov, S.G., 1966, Synthesis of optically active ion exchange resins., *Russian Chemical Bulletin*, 15(3), 510-512.
- [5] Yergozhin, Ye. , Ye., Abdrakhmanova, I. K., and Menligazyev, Ye. Zh., 1981, Synthesis and investigation of the properties of organosilicon anion-exchange resins., *Polymer Science U.S.S.R.*, 23(11), 2671-2678.
- [6] Sugii, A., Ogawa, N., Nozaki, Y., and Haratake, M., 1988, Preparation of macroreticular anion-exchange resins having spacers and an evaluation of these resins in the synthesis of sulfones., *Reactive Polymers, Ion Exchangers, Sorbents*, 8(1), 3-6.
- [7] Zaidi, S.A.R., and Shah, G.B., 2000, Synthesis of strongly basic anion exchange resins based on glycidyl methacrylate-ethylene glycol dimethacrylate copolymer. Effect of amount and nature of diluent, and the degree of crosslinkage on the resins properties., *Macromolecular chemistry and physics*, 201(18), 2760-2764.
- [8] Tomoi, M., Yamaguchi, K., Ando, R., Kantake, Y., Aosaki, Y., and Kubota, H., 1997, Synthesis and thermal stability of novel anion exchange resins with spacer chains., *Journal of Applied Polymer Science*, 64(6), 1161-1167.
- [9] Sood, D.D., 1998, *Proc. Int. Conf. on Applications of Radioisotopes and Radiation in Industrial Development*, ed. Sood, D.D., Reddy, A.V.R., Iyer, S.R.K., Gangadharan, S., and Singh, G., (B.A.R.C., India) 35-53.
- [10] Singare, P.U., and Lokhande, R.S., 2012, Studies on Ion-Isotopic Exchange Reactions Using Nuclear Grade Ion Exchange Resins., *Ionics*, 18(4), 351-357.
- [11] Lokhande, R.S., Singare, P.U., and Kolte, A.R., 2010, Application of Radioactive Tracer Technique for Characterization of Strongly Basic Anion Exchange Resins Duolite A 101D and Duolite A 102D., *Radiochemistry*, 52(1), 81-86.
- [12] Lokhande, R.S., Singare, P.U., and Tiwari, S.R.D., 2009, Application of  $^{82}\text{Br}$  as a Radioactive Tracer Isotope to Study the Bromide Ion-Isotopic Exchange Reaction in Strongly Basic Anion Exchange Resin Duolite - A161., *Russ. J. Physical Chemistry*, 83(8), 1389-1394.
- [13] Lokhande, R.S., Singare, P.U., and Tiwari, S.R.D., 2008, Study of Bromide Ion- Isotopic Exchange Reaction Kinetics Using a weakly Basic Macro porous Resin Indion -860., *Radiochemistry*, 50(6), 633-637.
- [14] Lokhande, R.S., Singare, P.U., and Parab, S.A., 2008, Application of Radioactive Tracer Technique to Study the Kinetics of Iodide Ion- Isotopic Exchange Reaction using Strongly Basic Anion Exchange Resin Duolite A-116., *Radiochemistry*, 50(6), 642-644.
- [15] Lokhande, R.S., Singare, P.U. and Patil, V.V., 2008, Application of Radioactive Tracer Technique to Study the Kinetics and Mechanism of Reversible Ion- Isotopic Exchange Reaction using Strongly Basic Anion Exchange Resin Indion -850., *Radiochemistry*, 50(6), 638-641.
- [16] Lokhande, R.S., Singare, P.U., and Prabhavalkar, T.S., 2008, The Application of the Radioactive Tracer Technique to Study the Kinetics of Bromide Isotope Exchange Reaction with the Participation of Strongly Basic Anion Exchange Resin Indion FF-IP., *Russ. J. Physical Chemistry A*, 82(9), 1589-1595.
- [17] Singare, P.U., Lokhande, R.S., and Patil, A.B., 2008, Application of Radioactive Tracer Technique for Characterization of some Strongly Basic Anion Exchange Resins., *Radiochim. Acta*, 96(2), 99-104.
- [18] Lokhande, R.S., and Singare, P.U., 2008, Comparative Study on Iodide and Bromide Ion-Isotopic Exchange Reactions by Application of Radioactive Tracer Technique., *J. Porous Mater.*, 15(3), 253-258.
- [19] Lokhande, R.S., Singare, P.U., and Patil, A.B., 2007, Application of Radioactive Tracer Technique on Industrial Grade Ion Exchange Resins Indion-830 (Type-1) and Indion-N-IP (Type-2)., *Radiochim. Acta*, 95(1), 111-114.
- [20] Lokhande, R.S., and Singare, P.U., 2007, Comparative Study on Ion-Isotopic Exchange Reaction Kinetics by Application of Tracer Technique., *Radiochim. Acta*, 95(3), 173-176.
- [21] Lokhande, R.S., Singare, P.U., and Kolte, A.R., 2007, Study on Kinetics and Mechanism of Ion-Isotopic Exchange Reaction Using Strongly Basic Anion Exchange Resins Duolite A-101 D and Duolite A-102 D., *Radiochim. Acta*, 95(10), 595-600.
- [22] Lokhande, R.S., Singare, P.U., and Dole, M.H., 2007, Application of Radiotracer Technique to Study the Ion Isotope Exchange Reactions Using a Strongly Basic Anion-Exchange Resin Duolite A-113., *Radiochemistry*, 49(5), 519-522.
- [23] Lokhande, R.S., Singare, P.U., and Karthikeyan, P., 2007, The Kinetics and Mechanism of Bromide Ion Isotope Exchange Reaction in Strongly Basic Anion-Exchange Resin Duolite A-162 Determined by the Radioactive Tracer Technique., *Russ. J. Physical Chemistry A*, 81(11), 1768-1773.

- [24] Lokhande, R.S., Singare, P.U., and Dole, M.H., 2006, Comparative Study on Bromide and Iodide Ion-Isotopic Exchange Reactions Using Strongly Basic Anion Exchange Resin Duolite A-113., *J. Nuclear and Radiochemical Sciences*, 7(2), 29-32.
- [25] Lokhande, R.S., and Singare, P.U., 2003, Study of reversible ion-isotopic self diffusion reaction using  $^{82}\text{Br}$  as a radioactive tracer isotope., *Asian J. Chem.*, 15(1), 33-37.
- [26] Lokhande, R.S., and Singare, P.U., 2005, Study on kinetics of self diffusion reaction by application of  $^{82}\text{Br}$  as a radioactive tracer isotope., *Asian J. Chem.*, 17(1), 125-128.
- [27] Shannon, R.D., 1976, Revised effective ionic radii and systematic studies of interatomic distances in halides and chalcogenides., *Acta Crystallographica*, A32, 751-767.
- [28] Heumann. K. G.. and Baier. K.. 1982. Chloride distribution coefficient on strongly basic anion- exchange resin: Dependence on co-ion in alkali fluoride solutions., *Chromatographia*, 15(11), 701-703.
- [29] Adachi, S., Mizuno, T., and Matsuno, R., 1995, Concentration dependence of the distribution coefficient of maltooligosaccharides on a cation-exchange resin., *J. Chromatography A*, 708(2), 177-183.
- [30] Shuii. A.. Takashi. M.. and Rvuchi. M.. 1996. Temperature dependence of the distribution coefficient of maltooligosaccharides on cation-exchange resin in  $\text{Na}^+$  form., *Bioscience, Biotechnology, and Biochemistry*, 60(2), 338-340.