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Selective Recovery of Scandium (Sc) from Sulfate Solution of Bauxite Residue Leaching by Puromet MTS9580 Ion-Exchange Sorption

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Abstract: Rare earth elements (REEs) and Sc are concentrated in aluminum production byproducts. The novel REEs recovery approach, which involves leaching by acid at a pH > 3 in the presence of $MgSO_4$, results in the formation of a pregnant leach solution (PLS) with a low concentration of iron (Fe) and titanium (Ti) and a large quantity of valuable elements. The ion exchange method was acknowledged as the most favorable method used to separate the REEs from PLS. This work studies the application of chelating resin Puromet MTS9580 in the sorption recovery of Sc from sulfate solutions. To analyze the static Sc sorption data, Langmuir, Freundlich, and Temkin isotherm models were used. The Langmuir isotherm model was the best fitted to the experimental data, with a coefficient of determination (R^2) of 0.983. The dynamic adsorption experiment was conducted using a PLS and a simulate solution without contaminants. Adsorption of Sc from the simulate solution was better fitted to the Thomas model with a Sc capacity greater than 7 mg mL^{-1}. Because Ti had a gradual decrease in C/C_0, which the Thomas model was unable to simulate, the modified dose-response (MDR) model fitted better with PLS. The $NaHCO_3$ solution (200 g L^{-1}) effectively desorbed Sc (>98 %) from simulated and PLS solutions after 1.5 h of stirring in a batch mode.

Keywords: chelating resin; Sc recovery; selective sorption; adsorption isotherm; sulfate solution; Puromet MTS9580; red mud

1. Introduction

Rare earth elements (REEs) and Scandium (Sc) are found in many secondary resources, including the bauxite residue (BR) from the alumina industry. During bauxite alkaline leaching in the Bayer process and during sintering with soda, the REEs are concentrating in BR and in dust from electrostatic precipitators (ESPD) [1]. Despite the toxicity, excessive alkalinity, and complex composition of aluminum production byproducts, treatment to recover REEs can overcome the negative impacts of these factors on the economy. Therefore, the concentration of rare earth elements must be taken into account when extending the laboratory study of BR processing to a larger scale.

Sc, which is estimated to have 70–80 % of world reserves in bauxites, is far more economically valuable than the rest of the present in BR REEs [2]. The environmental analyses of hydrometallurgical processes inducing higher flexibility, reduced energy consumption, and other aspects stimulate the development of technologies based on them [3,4].

The Sc concentrate obtaining process involves several different approaches, including the stage of leaching into the aqueous phase and the stage of selective recovery from the PLS. The extraction of target elements is commonly accomplished by aqueous solutions of mineral acids such as HCl, H_2SO_4 or HNO_3, as it ensures maximum extraction into the leachate. The obtained PLS is traditionally characterized by a high salt background, high acidity ($pH < 2$), and a low concentration of Sc. In order to concentrate the element and separate from lixiviants, the most established methods such as ion-exchange or solvent extraction are applied [3–5].

In solvent extracting (SX) to concentrate Sc from red mud processing solutions, organophosphorus solvents such as di-(2-ethylhexyl)phosphoric acid (D2EHPA/ DEHPA/HDEHP/P204) [6–9], tributyl phosphate (TBP) [7], bis(2,2,4 trimethylpentyl)phosphinic acid (Cyanex 272) [8] and 2-ethylhexyl phosphonic acid mono-2-ethylhexyl ester (HEHEHP/EHEHPA/PC-88A/Ionquest 801/P507) [9,10] are the most prevalent, defined by high selectivity to scandium. But even D2EHPA, the most used Sc solvent [11] with a high extraction capacity, has a low affinity for Sc when it is mixed with Ti, Th, other REEs, and several other impurity elements. Furthermore, the tendency of D2EHPA to emulsify leads to loss of the extracted component. On the contrary, substantial quantities of BR or acidic leach solutions that have been processed are accompanied by the irreversible consumption of the costly extraction reagents themselves [5].

Due to the easy separation between liquid and solid phases, adsorption through ion-exchange (IX) has been considered as an alternative technique, that is simple to apply, inexpensive, and has low hazardous emissions (gaseous, organic) [12]. The recovery of metals from dilute solutions can be achieved using sorbent materials, which include novel promising substances such as Solvent-impregnated Resins (SIR) and Levextrel resins, commonly referred to as TVEX [13].

Solvent impregnated resins (SIR) are prepared by loading or soaking the material in a solution of an organic solvent. The SIR matrix solvent will selectively recover metal ions from the leachate, and these ions will diffuse into the resin phase [14]. The alternative resin is Levextrel, which was produced by the polymerization of styrene and divinylbenzene macroporous copolymers in the presence of extractant, which was incorporated during the synthesis [15]. Based on some extractants used to recover scandium, the following impregnates and TVEX containing TBP (TVEX-TBP) [16], D2EHPA (VP OC 1026) [17], Cyanex 272 (TP 272) [18], PC 88A (Amberlite XAD 7HP resin) [19] were obtained and tested for the concentration of Sc in hydrometallurgical processing of various mineral raw materials and concentrates.

SIR combines both the beneficial and negative aspects of both the ion-exchange and liquid-liquid extraction in a polymeric-material adsorbent. SIRs can recover ions from very diluted solutions, but they have a low capacity and are prone to fouling, because of aqueous solubility [20]. TVEX, unlike SIR, cannot be washed out by acid solutions and requires a strongly acidic medium (up to 8M HCl or 6M H_2SO_4) for selective recovery [5,16]. Searching of optimum conditions, it had not been reported that such a medium would be selective for the separation of Fe and Al from Sc at the stage of sorption and desorption.

Since the majority of feed sources containing REEs are acidic, the strong acid cation resin (SAC) containing cations as counterions is the preferred choice for REEs and Sc recovery [21,22]. In order to obtain a mixed rare earth product at the adsorption of La, Sm, and Ho in the study [23], SAC demonstrated the following selectivity order in a wide-applicable sulfuric acid media: REE ≈ Th > Fe ≈ Al. However, it is known that SAC have higher selectivity towards LREEs rather than HREEs and Sc [24–26]. The absence of selectivity towards heavier lanthanides can be overcome by the presence of chelating ligands on anion exchangers.

The chelating resins were designed to overcome the limited selectivity of conventional anion and cation exchange resins. Numerous researchers have examined their potential application in the recovery and purification of individual REEs, and CR application is prevalent [18,23,27]. CR can adsorb REEs both from strongly acidic solutions (0.5–1.0 M) and from diluted solutions (at $pH > 3$) [23]. Bao et al. [18] showed that Sc (III) adsorption capacity on chelating resins decreases with increasing sulfate concentration because of the formation of the anionic sulfate complex. As more ammonium sulfate is added, the distribution coefficient of average lanthanides (La, Lu, and Sm) decreases faster than that of Sc in the study [28]. Nonetheless, further study is required to assess the practical applicability of these type of resins in a real sulfate environment. Furthermore, new chelating resins must be developed and studied in order to recover Sc from a sulfate-based solution.

It can be summarized that the shorter lifespan of SIRs and TVEX imposes limitations on their industrial application in comparison to the conventional and chelating ion-exchange resins. Despite the available data on the use of ion exchangers to recover REEs from BR leaching solutions, the search for new separation materials to improve selectivity towards Sc, minimize reagent consumption, and establish greener processes is still ongoing.

In our previous studies [29,30] of the processes of aluminum raw materials hydrometallurgical treatment, it was suggested that rare earth elements could be recovered from BR with the addition of $MgSO_4$ at the stage of selective acid leaching at $pH > 3$. Thus, it is possible to obtain a solution with a low content of Fe and Ti and a simultaneous high content of valuable elements. Since ion exchange sorption is the most favorable method for recovering Sc from complex PLS, this study extends our previous work and estimates Sc recovery from sulfuric acid solutions by chelating resin Puromet MTS9580.

2. Materials and Methods

2.1. Materials and Reagents

In this study, the chelating ion-exchange resin Puromet MTS9580 from Purolite® company was used for rare earth elements recovery from sulfuric acid leaching solutions. The resin is supposed to have functional groups of phosphonates [26], which are phosphonic acid derivatives in a polystyrene-divinylbenzene (St – DVB) matrix. Therefore, it has a selectivity to scandium and HREE against trivial impurities, such as Al (III) and Fe (III). The resin samples were converted from the chloride form by treatment with 100 g L^{-1} H_2SO_4 and deionized water until the pH of the eluate was neutral.

A simulated solution with a scandium concentration of 1–20 mg L^{-1} at a pH of 3.5 was prepared by dissolving Sc_2O_3 (with a purity of 99%) in dilute sulfuric acid. To evaluate the effect, specifically, of the presence of magnesium cations on the Sc adsorption under dynamic conditions, a certain amount of $MgSO_4$ (analytical grade) was added to the solution and continuously stirred until complete dissolution using a laboratory magnetic stirrer (Daihan Scientific Co., Ltd., Seoul, South Korea). The simulated solution contained 24 g L^{-1} of $MgSO_4$ and 10 mg L^{-1} Sc to approximate the data from real leaching solutions.

The required pH values were adjusted by adding 1 M H_2SO_4. The pH measurements were conducted using a portable pH meter HI 83141 (Hanna Instruments, Inc., Smithfield, RI, USA), which was equipped with a combined pH electrode HI 1230B.

The study of the adsorption of Sc in the column was conducted by utilizing a PLS that was obtained following sulfuric acid leaching of ESPDW (a solid phase or BR obtained after pre-leaching of ESPD by water) in the presence of magnesium cations [29]. The conditions of ESPD water leaching to maximize the concentration of REEs in ESPDW were previously investigated in [31]. The solution was prepared by leaching 400 g ESPDW with a sulfuric acid solution at the optimal parameters ($T = 80$ °C, $C_{MgSO_4} = 36$ g L^{-1}, liquid to solid ratio (L/S) = 10, and pH = 3.5) for 1 h. Table 1 shows the chemical composition of PLS. All the other reagents used were of analytical quality.

Table 1. The chemical composition of pregnant leaching solution (PLS) obtained by leaching of bauxite residue with a sulfuric acid solution at $T = 80$ °C, $C_{MgSO_4} = 36$ g L^{-1}, liquid to solid ratio (L/S) = 10, and pH = 3.5 for 1 h.

Element	Mg	Na	Ca	Si	Al	K	Fe	Sc	Ti
mg L^{-1}	7270.0	1809.38	621.12	286.3	274.10	281.3	50.74	12.31	1.58

2.2. Experimental

A weighed amount of resin was placed into a laboratory flask or column. Batch and column adsorption experiments were conducted on simulated solution and PLS at a room temperature of 22±2 °C.

The batch adsorption was conducted by mixing 50 mL of simulated solution containing a scandium in concentration of 1–20 mg L^{-1} at a pH = 3,5 with 0.1 mL of chelating resin in a conical flask for 8 h. In batch experiments, a rotary laboratory shaker PE-6410 (ECROS, Saint-Petersburg, Russia) was used to mix at a speed of 60 rpm.

The column adsorption was performed using a 3 mL plastic ion-exchange column. The ion-exchange experimental unit is shown in Figure 1. The resin volume in the column was 2 mL. The transmission rate of 2.5 to 7.5 mL min^{-1} during the adsorption was established using a peristaltic pump LOIP LS-301 (Laboratory Equipment and Instruments Ltd., Russia), which supplied the initial solution to the bottom of the ion-exchange column. Samples of ion-exchanged liquid that came out of the top of the column were taken periodically for analysis.

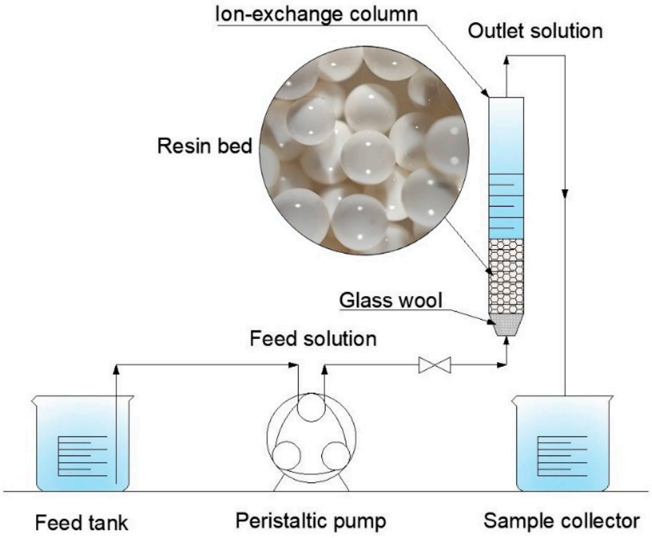


Figure 1. The column ion-exchange experimental unit.

The resins that were saturated were thoroughly rinsed with distilled water and then subsequently desorbed with a solution of 200 g L^{-1} Na_2CO_3 within a timeframe of 30 min to 2 h in a batch mode.

2.3. Analysis

The equilibrium ion concentrations of Sc (mg L^{-1}) and impurities in the resulting solution samples diluted with 5% HNO_3 were measured using an inductive coupled plasma optical emission spectroscopy (ICP-OES) via Vista Pro spectrometer (Varian Optical Spectroscopy Instr., Mulgrave, Australia) and atomic absorption spectroscopy (AES) via Varian AA-240FS spectrometer (Agilent Technologies, San Jose, CA, USA).

2.4. Calculating Methods

2.4.1. Adsorption efficiency calculations

The sorption capacity of the resin at equilibrium was calculated using Equation (1), where Q is the amount of the metal ions adsorbed onto the resin (mg g^{-1}), C_0 and C_t are the initial and equilibrium metal concentrations (mg L^{-1}), V is the volume of the solution (L), and V_r is the volume of the resin (mL).

$$Q = (C_0 \times C_t) \times V / \times V_r, \quad (1)$$

The desorption degree (D in %) was calculated using Equation (2):

$$D = \frac{m_{desorbed}}{m_{resin}} \times 100, \tag{2}$$

where $m_{desorbed}$ – mass of the element desorbed from the resin, g, m_{resin} – the mass of the sorbed element, g.

The distribution coefficient (K_d) and the separation factor ($\beta_{A/B}$) were calculated using Equations (3)-(4):

$$K_d = Q_d/C_e, \tag{3}$$

$$\beta_{A/B} = K_{d\,A}/K_{d\,B}, \tag{4}$$

where K_d is the ratio of the sorbed amount of metal divided by its equilibrium concentration in the solution (mL g^{-1}); β is the ratio of the distribution coefficient of two metals A and B ($K_{d\,A} \geq K_{d\,B}$).

2.4.2. Adsorption Isotherm Studies

To quantify the sorption process of Sc (III) in batch experiments the equations of two-parameter models of Langmuir (Equation (5)), Freundlich (Equation (6)) and Temkin (Equation (7)) were used.

$$Q = \frac{Q_m K_L C_e}{(1 + K_L C_e)}, \tag{5}$$

$$Q = K_F C_e^{\frac{1}{n}}, \tag{6}$$

$$Q = \frac{RT}{K_T} \ln A_T C_e, \tag{7}$$

where Q is the amount of adsorbed metal at adsorption equilibrium (g L^{-1}), Q_m is the maximum amount of adsorbed metal (g L^{-1}), C_e is the equilibrium concentrations of the element in solution (mg L^{-1}), K_L is the Langmuir isotherm constant, K_F and n are two constants of Freundlich model, K_T and A_T are two constants of Temkin model, R is universal gas constant (8.314 J mol^{-1}·K^{-1}), T is temperature (K).

2.4.3. Adsorption Column Studies

The dynamic adsorption system from PLS for MTS9580 resin was analyzed using the MDR and Thomas models in accordance with Equations (8)-(10): MDR model (Equation (8)), calculation of q_0 using the constant b of MDR model (Equation (9)), Thomas model (Equation (10)).

$$\frac{C_t}{C_0} = 1 - \frac{1}{1 + \left(\frac{V_t}{b}\right)^a}, \tag{8}$$

$$q_0 = \frac{bC_0}{V_r}, \tag{9}$$

$$\frac{C_t}{C_0} = \frac{1}{1 + e^{\left(\frac{K_t Q_0 V_r}{F} - K_t C_0 t\right)}}, \tag{10}$$

where C_t and C_0 are concentration in moment t and initial concentration (mg mL^{-1}), V_t is the outlet solution volume in moment t, a and b is MDR model constants, q_0 and Q_0 are maximum column loading metal capacity (mg mL^{-1}), V_r is volume of used resin (mL), K_t is Thomas constant (L min^{-1} mg^{-1}), q_0 is equilibrium adsorption capacity (mg g^{-1}), F is the volumetric flow rate of the column (mL min^{-1}). Model fitting was performed for Sc adsorption isotherms and breakthrough curves in OriginPro software using non-linear regression analysis.

3. Results and Discussion

For the recovery of Sc and rare earth elements from sulfate solutions, chelating resins are observed as the best choice [23]. The sorption capacity and selectivity of chelating ion exchangers are primarily influenced by the nature and relative position of the functional groups. Chelating ligands, especially those containing phosphorus, are of particular interest. In acidic systems, chelating resins with phosphonic functional groups adsorb rare earth elements, U and Fe and make it possible to separate Sc micro quantities from other REEs [32]. Marhol et al. [33] have discovered that the phosphinic ion exchangers exhibit a strong affinity for scandium (III), which is consistent with the affinity series: Sc (III) > Fe (III) > In (III) > Ga (III) > Al (III) > La (III).

The ion-exchange resin was chosen based on its functional groups, affinity, and selectivity with respect to scandium. Even though the REEs (III) ion-exchange with these complexes is still a poorly studied area, as indicated by the literature data, the REEs distribution efficiency from sulfate-based solutions on resin is as follows: chelating resin > strong anion resin > strong cation resin. The stability of the sulfate complexes is not apparent to be dependent on the REE (III) ion radius, with the exception of Sc, which exhibits a significantly higher distribution coefficient than the rest elements [17,34]. It is possible to separate scandium from other elements because many elements, as well as rare earths, have slight or no adsorption on anion exchange resins from sulfate or sulfuric acid medium.

According to thermodynamics, Sc forms positive and negative stable charged complexes in sulfate media. The main forms of Sc existence in solution are complexes of the anionic type $[Sc(SO_4)_2]^-$, $[Sc(SO_4)_3]^{3-}$ (pH range 1.6-6.0) [24,35]. As concentration of sulfate ions in an aqueous solution increases, Sc anionic forms become dominant, thus decreasing Sc adsorption capacity on weak cation exchanger (WAC) with chelating amino methyl phosphonic acid groups [18]. For trivalent REEs, only the $[LnSO_4]^+$ and the $[Ln(SO)_4]^{2-}$ complexes where the cation type is recognized as dominant were identified [36,37]. Thus, Sc behavior in sulfate media combined with selective desorption is crucial for designing a new effective approach.

3.1. Batch Sc adsorption Experiments and Study of Sorption Mechanism

The batch adsorption experiments were carried out on simulated solutions with a concentration of 1-20 mg L^{-1} Sc. Based on the obtained results, a sorption isotherm was constructed (Figure 2). Obtained results indicate a high affinity of the chelating ion-exchange resin for this particular type of adsorbed ions. Following the thermodynamic models' equations, the static sorption data were analyzed using the Langmuir, Freundlich, and Temkin isotherm models (Figure 2). For each model, the primary thermodynamic parameters of the sorption equilibrium and the values of the multiple correlation coefficients R^2 (Table 2) were obtained.

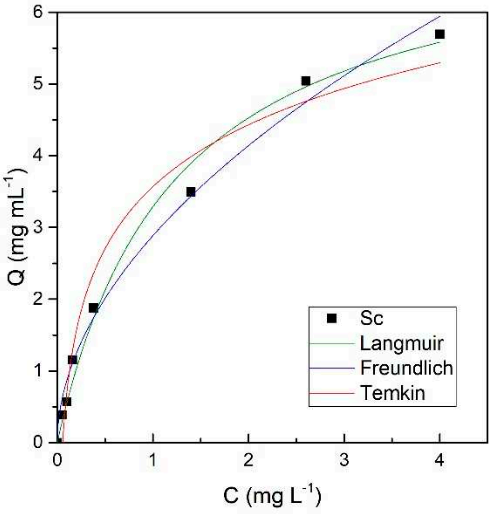


Figure 2. Langmuir, Freundlich and Temkin adsorption isotherm obtained for Sc adsorption on MTS9580 from simulated sulfuric acid solutions at pH 3.5.

Table 2. The isotherm parameters for Sc adsorption on MTS9580 from simulated solutions at pH 3.5.

Model	**Langmuir**			**Freundlich**		**Temkin**	
Parameter	R^2	Q_m, g L^{-1}	K_L, L mg^{-1}	R^2	K_F, L mg^{-1}	R^2	K_T, L mg^{-1}
Value	0.983	8.576	0.985	0.975	3.440	0.963	1615

The Langmuir model was successfully applied to describe the Sc adsorption by the ion-exchange resin with $R^2 = 0.983$. According to the Langmuir equation, the capacity constant $K_L = 0.985$, while the maximum calculated capacity Q_m = 8.576 g L^{-1}. The Langmuir isotherm is generally suited for describing the chemisorption process on chelating ion-exchange resins, wherein ionic or covalent chemical bonds are formed between the adsorbent and the adsorbate.

3.2. Column Adsorption and Breakthrough Modelling

3.2.1. Adsorption study from simulated solution

The ion breakthrough of the simulated solution was analyzed using the following breakthrough models, which are commonly applied to ion-exchange data based on the mass of the resin. MDR model and Thomas model.

Equations (8) and (9) [38] are used to apply the MDR model to ion-exchange breakthrough data. Using Equation (9), the maximum column loading capacity for each metal (Q_0) can be estimated by assessing MDR model data. Furthermore, the MDR model generally reduces the error resulting from the Thomas model, especially when the breakthrough curve is shorter or longer.

The Thomas model (Equation (10)) assumes that the process follows the Langmuir adsorption/desorption kinetics without axial dispersion [39], and that the uptake is adjusted by pore-diffusion kinetics [40]. The main advantage of this model is its ability to predict breakthrough curves under different operating conditions.

The adsorption experimental data at different flow rates of 2.5, 5, and 7.5 mL per minute are shown in Figure 3, where C/C_0 is the ratio of Sc-ion concentrations in the collected effluent over the feed solution. Base parameters and model constants (Kt, a, b) are shown in Table 3.

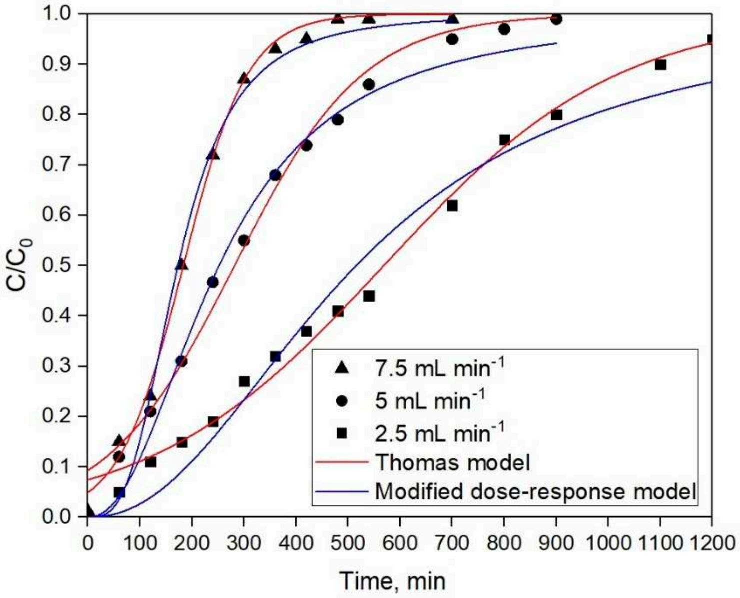


Figure 3. Column adsorption of Sc from a simulated solution on MTS9580 at flow rate 2.5-7.5 mL min^{-1}.

Table 3. Thomas and MDR model parameters for Sc adsorption on MTS958 from a simulated solution at different flow rates.

Thomas model	**2.5 mL min^{-1}**	**5 mL min^{-1}**	**7.5 mL min^{-1}**
K_t (L min^{-1} mg^{-1})	0.00142	6.834×10^{-4}	3.65×10^{-4}
Q_0 (mg mL^{-1})	7.013	6.776	6.383
R^2	0.99	0.989	0.996
Modified dose-response model	**2.5 mL min^{-1}**	**5 mL min^{-1}**	**7.5 mL min^{-1}**
a	2.197	2.184	3.115
q_0 (mg mL^{-1})	10.214	4.845	3.213
R^2	0.973	0.987	0.988

The results in Figure 3 and Table 2 suggest that the breakthrough data fits well with the Thomas model with correlation coefficients higher than 0.99 for 2.5 mL min^{-1} flow rate. The maximum adsorption capacity of Sc calculated according to Thomas model was 7.013 mg mL^{-1}, which is close to the measured (based on the final solution) value of 6.7 mg mL^{-1}. According to the MDR model, this value was too high (10.214 mg mL^{-1}). As the dynamic capacity of the resin for Sc decreased slightly (to 6.3 mg mL^{-1}) upon increasing the flow rate to 7.5 mL min^{-1}, this flow rate was selected for experiments utilizing PLS.

3.2.1. Adsorption study from PLS

The metals adsorption from a PLS containing 12.3 mg L^{-1} of Sc, 50.7 mg L^{-1} of Fe, and 1.6 mg L^{-1} of Ti at a flow rate of 7.5 mL per minute was evaluated. Figure 4 shows the obtained breakthrough curves.

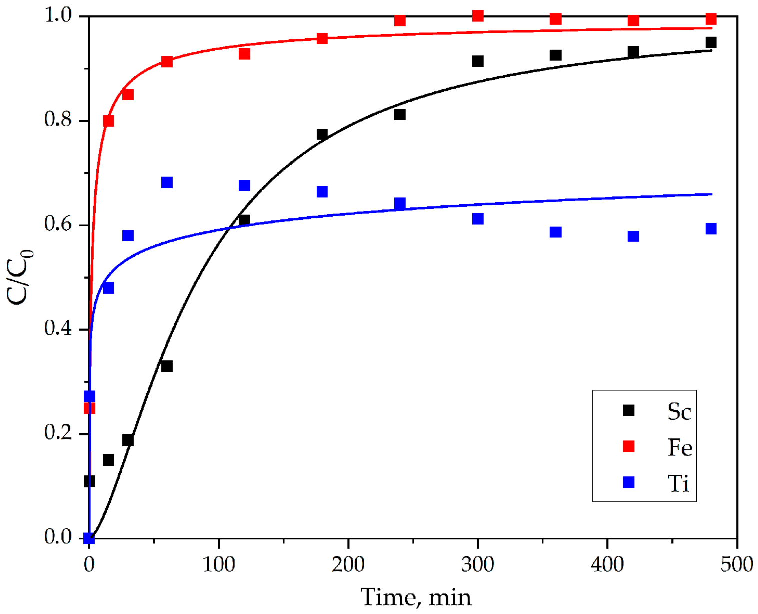


Figure 4. MDR model column adsorption on MTS9580 at PLS flow rate 7.5 mL min^{-1}.

Compared to a simulated solution, the MDR model had a better fitting result with PLS, since a gradual decrease in C/C_0 was observed for Ti, which could not be fitted using the Thomas model. The model constants and the dynamic resin capacity calculation results for the MDR model are shown in Table 4.

Table 4. MDR model parameters of column adsorption on MTS9580 from PLS.

MDR model	Sc	Fe	Ti
a	0.679	1.532	0.187
q_0 (mg mL^{-1})	3.888	0.343	0.082
R^2	0.984	0.997	0.905

The adsorption of Fe (III) was observed at the initial moment, but after 100-200 min there was no further adsorption. In addition to the adsorption of Sc on the resin, a significant adsorption of Ti was observed, which is believed to be attributable to the similarity of Ti properties to REEs [35]. However, due to the selective nature of leaching, the concentration of Ti in solution does not exceed 1.6 mg L^{-1}, resulting in a very low capacity for Ti. Based on the column experiments, the dynamic exchange capacity (Q_d), the distribution coefficient (K_d) and the separation factor ($\beta_{Sc/Ti,Fe}$) were calculated (Table 5).

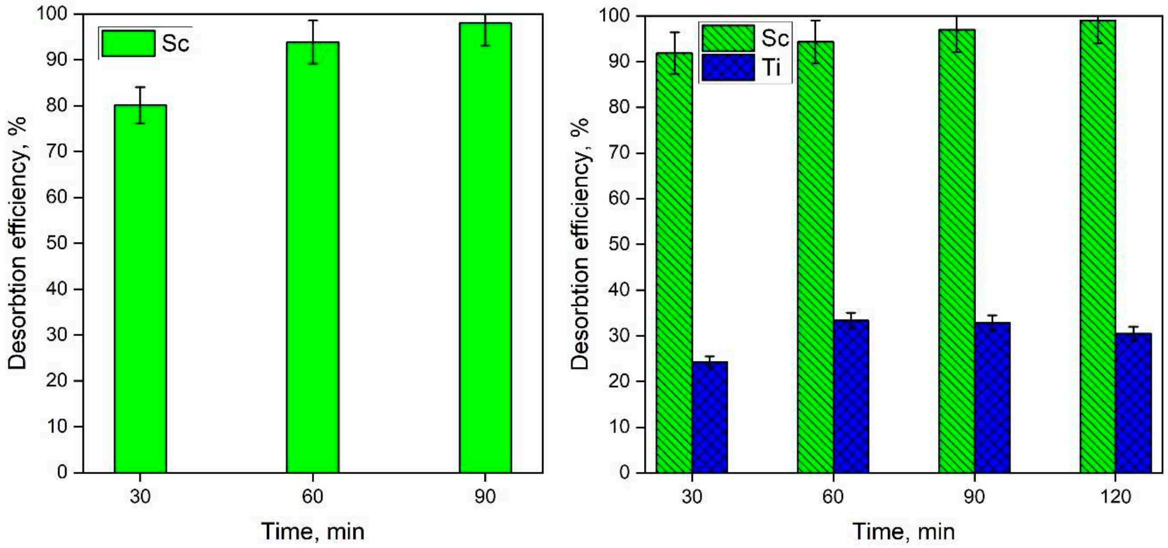
Table 5. Results for Sc, Ti and Fe column adsorption on MTS9580 from PLS.

Element	Sc	Ti	Fe
$\beta_{Sc/E}$	-	0.25	6.90
K_d (mL g^{-1})	0.40	1.61	0.06
Q_d, mg mL^{-1}	3.77	1.14	2.81

The high affinity of the Puromet MTS9580 ion-exchange resin for Sc is confirmed by the Q_d and K_d values for Sc (III), as well as the high $\beta_{Sc/E}$ value for Fe (III), despite the fact that the Fe concentration in the solution was four times greater than the Sc concentration.

3.3. Desorption Studies

It is also important to evaluate the desorption efficiency of the adsorption process. It is known that adsorbed Sc can be effectively desorbed from the resin by sodium bicarbonate solution, a kind of relatively economic desorbent. For saturated Puromet MTS9580 resin, the scandium desorption was caried out at room temperature for 30, 60, 90, and 120 min. The results are presented in Figure 5.



(**a**) (**b**)

Figure 5. Desorption efficiency by $NaHCO_3$ solution (200 g L^{-1}) from MTS9580, saturated using: a model solution (a); PLS (b).

The results in Figure 5(a) show that 98% of Sc from saturated by using a simulated solution resin can be desorbed within 1.5 h. The degree of desorption reached 80% after 30 min. After 1.5 h of desorption, the final eluate contained up to 562 mg L^{-1} of Sc, while the Mg concentration was below 190 mg L^{-1}. This indicates that the resin is very selective towards Sc or rare earth elements, since the concentration of Mg in the initial sulfate solution was 1000 times higher.

Figure 5(b) indicates that scandium desorption above 90 % from can be achieved within 30 min, and that almost complete Sc desorption occurs within 2 h. The degree of Ti desorption was less than 40%, and the concentration of Fe in the eluate was below 20 mg L^{-1}. The desorption data of resin saturated by using PLS showed that the concentration of Mg and Ti was lower than 200 mg L^{-1} and 50 mg L^{-1}, respectively (Table 6).

Table 6. The chemical composition of eluate after desorption of MTS9580, saturated using PLS.

Element	Sc	Mg	Ti	Fe	Y	La	Ce	Nd	Sm	Th
mg L^{-1}	461.5	195.9	48.8	16.1	9.4	4.3	6.2	5.0	1.9	1.2

After Sc desorption and washing by deionized water the resin was regenerated with a sulfuric acid solution with a concentration of 200 g L^{-1}, and the degree of the remaining elements desorption exceeds 95%, i.e. almost complete resin regeneration was achieved. The regeneration sulfate solution can be used to leach new portions of BR (Figure 6).

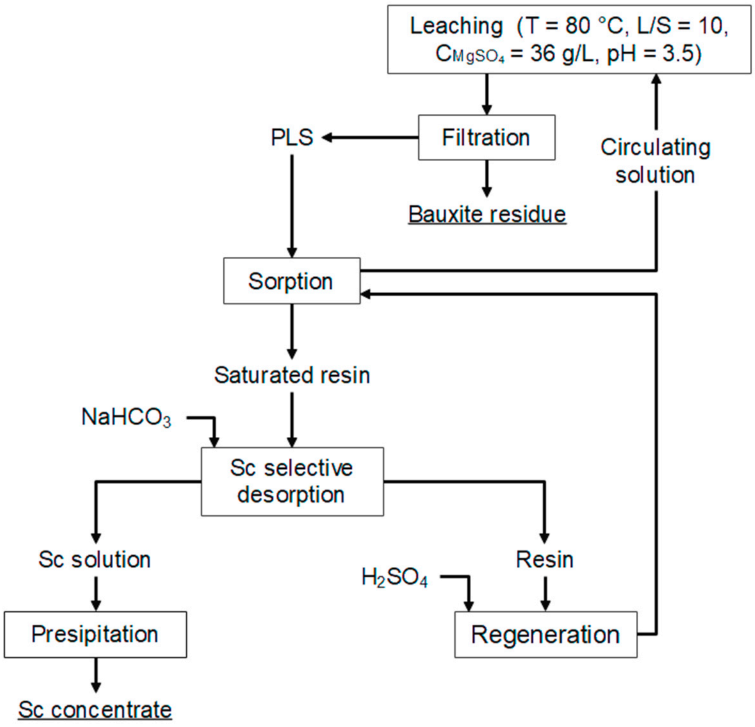


Figure 6. The principal flowsheet of Sc concentrate obtaining from PLS by Puromet MTS9580 ion-exchange sorption.

4. Conclusions

Based on the findings obtained from the present research, the predominant mechanism of sorption from simulated and pregnant leach solutions was examined on the chelating ion-exchange resin Puromet MTS9580. It is proposed to recover Sc first, since it is more expensive than the rest of the BR elements.

1. For the adsorption of Sc on resin, Langmuir equations adequately describe the sorption isotherms under batch conditions. This indicates the chemisorption process on the chelating resin.
2. The high values of R^2 for the equations of the breakthrough models indicate that the Thomas model is applicable to describing the Sc adsorption from simulated Mg-containing solutions. According to Langmuir model, the maximum calculated capacity for batch process was 8.576 g L^{-1}, while the maximum capacity for column sorption obtained using the Thomas model was 7.013 mg mL^{-1}.
3. The results of the column adsorption study using PLS showed that significant sorption of Ti in addition to Sc was observed. This is apparently due to the properties of Ti being close to the properties of REEs.
4. Sc can be efficiently desorbed (>98%) by $NaHCO_3$ solution (200 g L^{-1}) from both simulated and real solutions within a duration of 1.5 h. After 1.5 h of desorption, the concentration of Sc in the desorption solution was 562 mg L^{-1}, while the concentration of Mg and Ti was lower than 200 mg L^{-1} and 50 mg L^{-1}, respectively. This indicates that the resin is very selective towards Sc or rare earth elements.

The high affinity and selectivity of Puromet MTS9580 make it a promising sorbent for the recovery of scandium from PLS of selective leaching of BR. The obtaining of Sc and other REEs concentrates from the desorption solutions will be discussed in future studies.

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