

SORPTION AND DESORPTION OF RHENIUM IONS BY LIGNIN SORBENTS

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ABSTRACT

The present research focuses on the sorption, the kinetics and the regeneration properties of macroporous lignin ion-exchangers toward rhenium ions depending on the nature and the concentration of the functional groups of the ion-exchangers and the eluents, the metal ions and the acid concentration in the solution, the duration of the sorption and desorption processes and the number of the feasible sorption/desorption cycles. The optimum conditions of perrhenate ions sorption and desorption are established. It is found that among all of the used eluents viz., H_2SO_4 of a different concentration, 10 % NH_4OH , 1N NaOH, and 1N H_3PO_4 , the solution of 2N H_2SO_4 is the most effective eluent for extracting the trapped metal ions from lignin ion-exchangers. It is found that the ion-exchanger containing polyethyleneimine groups is regenerated better than the other one and found to be suitable for reuse in successive adsorption-desorption cycles ten times without a significant loss in the performance. The results suggest that this ion-exchanger can be used as an adsorbent for the efficient removal of rhenium ions from sulfate solutions.

Keywords: lignin ion-exchanger, rhenium ions, sorption, desorption, regeneration.

INTRODUCTION

Rhenium, one of the rarest and most dispersed of the metallic elements, that has long ago come into significant industrial use, has properties excellently suited for application as a refractory metal, as an alloying element, in high-temperature thermocouples, in electronic components, and as a catalyst in petroleum refining [1]. It does not occur in its native or pure state but only in combination with other elements, and no definite rhenium minerals have yet been identified [1, 2]. Commercial rhenium is obtained today in Kazakhstan from copper, lead, uranium, molybdenum, and polymetallic concentrates, tailings from ore concentration and sulfation industrial roaster-flue dust obtained from ores mined in Central, East and South Kazakhstan (mainly Zhezkazgan deposit in Karagandy Province) [3 - 10]. Due to the large amounts of rhenium-containing raw materials, our country is the largest producer of rhenium from primary mineral resources among the countries of the Eurasian Customs Union and the fifth-ranked producer of rhenium in the world (5 % of world output) [3 - 6].

Rhenium is recovered in Kazakhstan as ammonium perrhenate from solutions of copper, molybdenum and lead workshops [5 - 10]. Sorption and ion-exchange techniques are widely used for extraction of perrhenate ions from large volumes of multicomponent sulfate, nitrate, chloride solutions and industrial wastewaters obtained from leaching of concentrates and products of their processing, sulfation industrial dust and other wastes [2,4] using imported active carbons based on coal-tar [11] and plant raw materials [12], synthetic anion-exchangers from styrene-divinylbenzene (DVB) copolymers (AN [10,13-18], AV, [16], Purolite A170 [19-21], Ambersep A920U [22], Purolite A172 [21], Purolite PF172 [21], Purolite A105 [17], Purolite A143 [17], etc.), polyacrylates (Purolite A830 and Purolite A835 [17], Lewatit MP62 [20,21]) and polyvinyl pyridines (VP [13, 16]).

Most of the current studies demonstrate the use of AN-21, AN-21x14, AN-105-12P, VP-14KR, VP-18KR, Purolite A170, Purolite A172, Purolite PF172 and coals in sorption of rhenium ions from molybdenite roasting dust leaching solutions [10, 13-15, 19]. The main pur-

pose of such extraction is to reach not only a maximum concentration of rhenium but also a selective separation of rhenium from molybdenum [10]. The technology of rhenium removal from the scrub solution of copper production is improved in Balkhash copper mining-metallurgical plant (Kazakhmys plc) by using AN-21 Russian ion-exchanger and active coal [10]. A developed two-stage technique includes sorption of rhenium on a coal and subsequent selective removal of rhenium ions on AN-21 that acts as molecule sieve adsorbent providing selective separation of rhenium from molybdenum. The discovered sieve effect provides the development of a novel highly cross-linked ion-exchanger AN-21x14 (an analogue of AN-21). It is used for the first time for selective rhenium extraction in "Pobedit" plant (Vladikavkaz, North Ossetia) [14, 15].

Further investigations show some advantages of porous ion-exchangers in comparison with highly cross-linked gel structured sorbents. It is found that porous AN-105-12P in contrast to AN-21 has a higher sorption ability and selectivity for the separation of rhenium from molybdenum [13]. The sorption and desorption properties of weakly basic gel and porous anion-exchangers Purolite A172 and Purolite PF172 prepared from macroporous anion-exchanger Purolite A170 containing the same functional groups are studied aiming to expand the range of the sorbents for rhenium extraction. The results testify that both sorbents have a high selectivity with respect to rhenium, but porous ion-exchanger Purolite PF172 possesses better desorption properties than Purolite A172.

Rhenium is also extracted from copper production solutions by using active carbons and different kinds of weak and strong basic anion-exchangers based on gel and porous styrene-DVB and vinylpyridine-DVB copolymers [16, 23]. The results referring to rhenium sorption from washing acid solutions of copper-nickel production clearly demonstrate that the porous anion-exchanger AN-105-12P is the most effective sorbent among those studied. Its effectiveness is higher than those of the gel ion-exchangers AV-17 and AMP. It is also found that macroporous ion-exchanger Purolite A170 is highly selective in respect to rhenium removal from multicomponent zinc, copper, nickel and iron-containing solutions. The sorbent shows in addition improved kinetic properties due to its highly permeable macroporous structure.

Macroporous ion-exchangers are the most efficient in the technology of secondary rhenium production, which grows recently more than the primary production mainly due to the increased availability of the superalloy scrap. Purolite A170 and VP-14P are effectively used in commercial rhenium production on the ground of etching and sulfuric acids solutions obtained by processing of platinum-rhenium catalysts [17, 18]. The data shows that macroporous ion-exchangers AN-105P and VP-14P have better sorption properties towards rhenium than gel ion-exchangers AN-21, AN-82, VP-14KR, Purolite A105, Purolite A143, Purolite A830 and Purolite A835.

It is well known that the final rhenium-containing products include ammonium perrhenate [2-8]. The purification of crude ammonium perrhenate solutions from potassium is studied [24] using KU-2 Russian cation-exchanger. The method is tested on a pilot scale using a batch of commercial crude ammonium perrhenate salt. This technology is successfully applied at one of the biggest enterprises of Kazakhstan, i.e., Zhezkazganredmet.

As pointed out, Kazakhstan has huge resources of rhenium but does not have its own production of sorbents. The rhenium ions are extracted using expensive imported sorption materials. It is extremely important to develop cheap domestic ion-exchangers of improved sorption ability for effective removal of rhenium from metallurgical plants solutions. The aim of the present work is to study the sorption and desorption properties of novel macroporous ion-exchangers based on the hydrolysis industry by-product – hydrolytic lignin of cotton husk (HL) in relation to perrhenate ions.

EXPERIMENTAL

Ion-exchangers preparation and characterization

Anion-exchangers were prepared by a two-step process including condensation of HL with epichlorohydrin oligomer and subsequent amination of the obtained lignin chloro derivative using polyethyleneimine (HL-PEI), polyethylene polyamine (HL-PEPA), and 2-vinylpyridine (HL-2-VP). The synthesis of the lignin chloro derivative was carried out by mixing the extracted HL (1.0 g) with 50 % benzene solution of epichlorohydrin oligomer (6 mL) in a three-necked flask (50 mL) equipped with a mechanical stirrer, a thermometer, and a reflux condenser. The reaction mixture was vigorously stirred for 1.5 h at 60°C. The intermediate product was purified by extraction with benzene in a Soxhlet ap-

paratus after 5 h - 6 h and dried in a vacuum oven at 25°C. The amination of the lignin chloro derivative (1.0 g) with 30 % dimethylformamide solution of amines (5 mL) proceeded for 1 h at 80°C. The final amine products were subsequently solidified in porcelain crucibles in a muffle oven for 10 h at 80°C. They were washed with 5 % HCl and then kept in 5 % NaOH aqueous solutions for 24 h at room temperature. After each treatment the modified lignin samples were treated with distilled water and dried in a vacuum oven at 50°C.

The static exchange capacity (SEC) of the ion-exchangers and the apparent dissociation constant pK of their ionic groups were determined as described in ref. [25]. The specific volume (V_s) of the samples was established after their keeping for 24 h in distilled water. It was calculated as the ratio of the volume of the swollen sample (mL) and the mass of the dry polymer (g).

The characteristics of the lignin ion-exchangers are presented in Table 1.

Methods of analysis

The sorption was carried out under static conditions from ammonium perrhenate solutions at a sorbent to a solution ratio of 1:400. The initial and the equilibrium concentration of the rhenium ions in the solution was determined by the polarography method. The polarograms were registered on PU-1 polarograph in cells thermostated at $25 \pm 0.5^\circ\text{C}$ in 0.5N H_2SO_4 ($E_{1/2} -0.50\text{ V}$) as a supporting electrolyte. A saturated calomel electrode was used as a reference electrode. The oxygen was removed by bubbling argon through the solutions for 5 min.

RESULTS AND DISCUSSION

The sorption capacity (SC) of the lignin ion-exchangers in relation to rhenium ions depends on different factors such as the nature of the polymer matrix

Table 1. The characteristics of lignin ion-exchangers.

Sample	Element composition, %					SEC in 0.1N HCl, mEq/g		pK	V_s , mL/g	Yield, %
	C	H	O	Cl	$N_{\text{elem}} / N_{\text{titrable}}$	HCl	NaCl			
HL-PEI	54.7	7.9	25.7	-	11.64 / 9.94	6.5	0.6	6.20	5.25	90.3
HL-PEPA	56.4	7.5	25.7	-	10.37 / 7.81	5.18	0.4	5.65	4.75	90.9
HL-2-VP	61.2	6.9	24.5	1.42	6.06 / 4.62	-	3.30	2.15	3.50	81.2

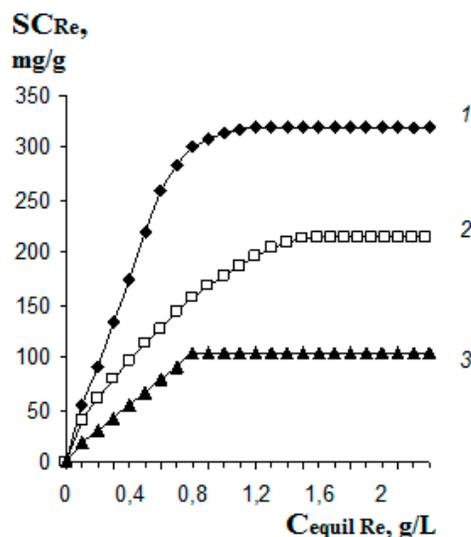


Fig. 1. Sorption isotherms of perrhenate ions on HL-PEI (1), HL-PEPA (2) and HL-2-VP (3) ion-exchangers.

and the functional groups, the concentration of the metal ions, the solution pH, the duration and the temperature of the sorption, etc. [26 - 28]. As seen in Fig. 1, the SC of the ion-exchangers increases with the increase of the metal concentration in the solution. This is probably due to the Donnan effect: the higher ions concentration in the solution, the greater amount of ions penetrates from the surface layer into the polymer grains. The sorption curves in $\text{SC}-C_{\text{equil}}$ coordinates allow not only to establish the equilibrium concentration of the ions in the solution where the sorbents are saturated but also to estimate their selectivity. It is so because the isotherm in these coordinates is one of the selective adsorption indicators [4]. According to the theoretical concepts, the greater the slope of a curve, the higher the specificity is. The isotherms show that the sorption properties and the selectivity of the ion-exchangers towards perrhenate ions decrease in the following order: HL-PEI > HL-PEPA > HL-2-VP > AN-21. This regularity is determined by the

concentration and the nature of the functional groups responsible for the metal ions binding. According to this order AN-21 ion-exchanger, widely used in the technology of rhenium extraction from industrial solutions, has the least capacity. The SC of AN-21 reaches a value of 1.29 mEq/g (or 34.27 mg/g) at a metal concentration of 0.93 g/L in the solution [28]. The SC values of the lignin anion-exchangers containing PEI, PEPA, and 2-VP groups are much higher than that of AN-21 under identical conditions. They refer to 8.75 (232.8 mg/g), 4.89 (130 mg/g) and 4.19 mEq/g (111.6 mg/g), respectively.

Fig. 1 testifies that the rhenium adsorption curves are typical Langmuir isotherms [29]. The sorption equilibrium can also be described by the stepwise Langmuir isotherm in $SC-\sqrt{K_D}$ coordinates [30, 31]. Such anamorphosis allows measuring the maximum values of K_D and equilibrium capacity by a continuation of the curve until crossing with SC and $\sqrt{K_D}$ axes. In addition, the shape of the curves in these coordinates is suitable for mathematical analysis of the results and provides information on the sorption mechanism.

Fig. 2 shows several rectangular segments on the isotherms anamorphoses. The multistage character of these curves testifies the polyfunctional character of the ion-exchangers. The non-linear character of the curves is probably explained by both sorption mechanisms: ion-exchange and complex forming processes. The possibility of rhenium ions complexation with active groups

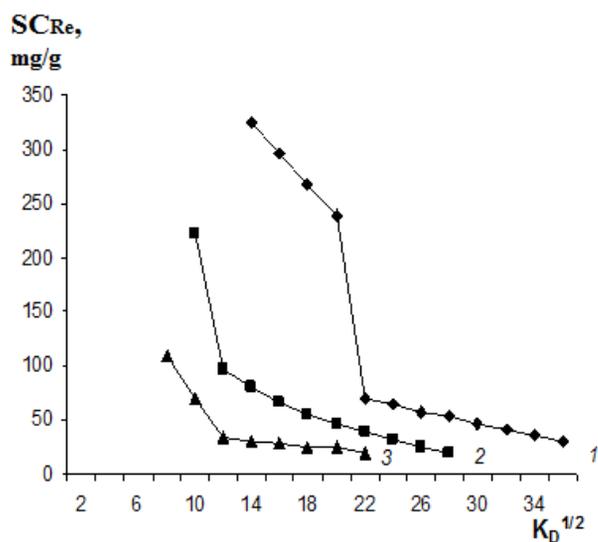


Fig. 2. Anamorphoses of the isotherms of perrhenate ions sorption by HL-PEI (1), HL-PEPA (2) and HL-2-VP (3) ion-exchangers.

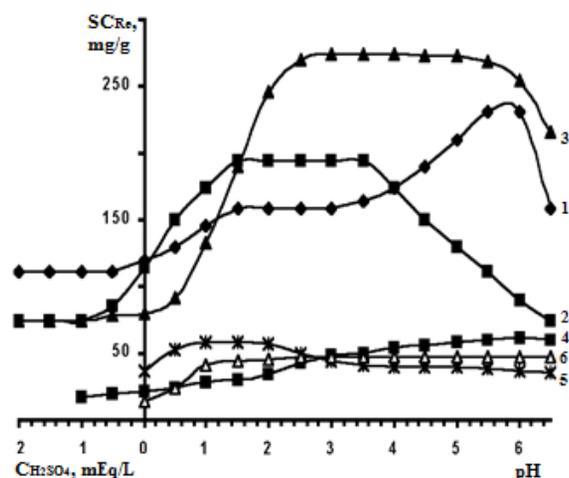
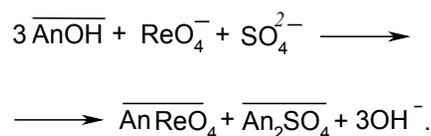


Fig. 3. Effects of solution pH and H_2SO_4 concentration on sorption properties of HL-PEI (1), HL-PEPA (2) and HL-2-VP (3) lignin ion-exchangers and commercial ion-exchangers AN-21 (4), AN-18 (5) and AV-16 (6) ($C_{Re} = 1$ g/L; $\tau = 24$ h).

of the sorbents is confirmed by their incomplete elution from the polymer matrix of some ion-exchangers such as pyridine-type anion exchange resins [26]. The strong binding of the ions indicates the increased affinity of Re to the polymers functional groups. It can be partially caused by the donor-acceptor interaction of the metal ions with the valently saturated groups of the sorbents (amine groups, a pyridine ring, etc.).

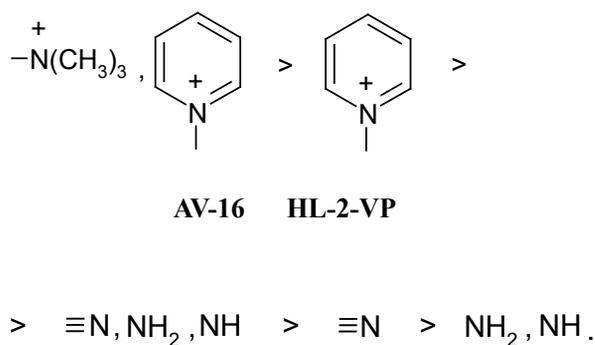
The rhenium sorption efficacy depends on the solution acidity. It is well known [4] that Re ion in neutral, acidic and alkaline solutions is present in the form of simple singly charged ReO_4^- anion. It means that the two factors, i.e. the protonation degree of the amine groups and the competitive sorption of the acid residual anions influence the capacity of the sorbents in the solutions of a different pH value:



As seen in Fig. 3, the pH region of the maximum sorption activity of the weak and medium basic ion-exchangers correlates with their basicity (Table 1): the lower the basicity, the higher is the pH value of their maximum adsorption. The highest sorption ability of the weak basic ion-exchanger AN-21 containing only primary and secondary amine groups occurs at pH 3 - 6

[26]. Further decrease or increase of solutions pH leads to a decrease of SC. The maximum Re adsorption in case of AN-18 ion-exchanger containing only tertiary amine groups (synthesized by amination of a styrene-DVB copolymer with dimethylamine) occurs at pH 1 - 3. The highly basic ion-exchangers AV-16 and HL-2-VP containing quaternary ammonium and pyridinium groups can adsorb rhenium ions in a wide range of pH (from 2.0 to 6.0) [26].

The medium basic polyfunctional lignin ion-exchangers demonstrate the predominant groups' properties. According to the pK values of the sorbents (Table 1), HL-PEPA (pK 5.65) is more basic ion-exchanger than HL-PEI (pK 6.16). The active primary and secondary amine groups in its structure have a slight effect on pK due to the stronger effect of the more basic tertiary amine groups. For this reason, HL-PEPA ion-exchanger as AN-18 is the most active at pH in the range of 1.5–3.5. HL-PEI adsorbent containing mainly NH_2 - and NH - groups is similar to AN-21 and like it removes efficiently the rhenium ions in nearly neutral solutions (pH of 5 - 6). The basic properties of the ion-exchangers decrease in the following order:



HL-PEI, HL-PEPA AN-18 AN-21

The further increase of the solution's acidity leads to a decrease of the ion-exchangers sorption ability due to the competitive sorption of the accompanying sulfate ions. The data shows a substantial decrease of SC values of lignin ion-exchangers up to 71 mg/g - 110 mg/g at H_2SO_4 concentration increase from 0.5 N to 2.0 N. The further acid concentration increase does not lead to SC decrease at all, whereas SC of AN-21 declines sharply to 16.5 mg/g. These results demonstrate that perrhenate ions are effectively removed from strongly acidic solutions by weak and medium basic sorbents such as AN-21 [4].

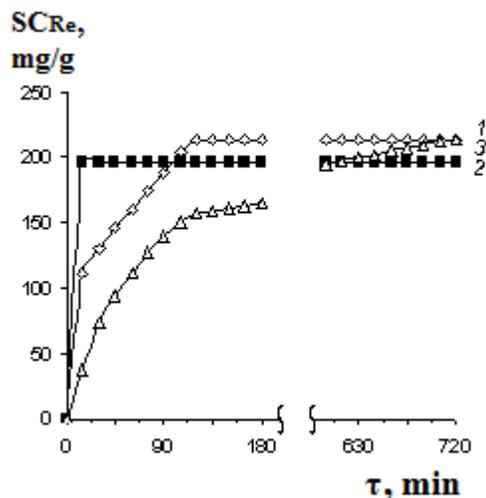


Fig. 4. Effect of the contact time on perrhenate ions removal by HL-PEI (1), HL-PEPA (2) and HL-2-VP (3) ion-exchangers at pH 5.0 (1), 2.37 (2), 1.59 (3). $C_{\text{RE}} = 1 \text{ g/L}$.

Fig. 4 illustrates the kinetic properties of the ion-exchangers. The complete sorption equilibrium on HL-PEPA is rapidly reached within 15 min. On HL-PEI and HL-2-VP ion-exchangers it is established for 2 h and 12 h, respectively. A large amount of rhenium ions (more than 70 % of the total amount of the adsorbed ions) is extracted during the first 1 h - 2 h. The comparatively worse kinetic properties of HL-2-VP are probably due to steric effects caused by shielding of the active nitrogen atoms by pyridinic groups and epichlorohydrin oligomer fragments in the polymer phase where the functional groups are blocked by two bulky substituents. It leads to weakening of the coulomb attraction between the fixed charged groups and the perrhenate counter ions which decreases the capacity and the kinetic properties of the ion-exchanger.

It is established that the equilibration time on AN-21 depends on the cross-linking degree of the polymer matrix. It is equal to time intervals from 2 h to 5 h, from 4 h to 29 h, and 77 h at DVB content of 2 %, 10 % and 20 %, respectively [27]. The considerable differences in the kinetic properties of the novel macroporous lignin ion-exchangers and the gel sorbents based on crosslinked styrene-DVB copolymers are apparently explained by the permeability of the polymer matrix and the availability of their functional groups.

The electron-beam-induced-current micrographs of

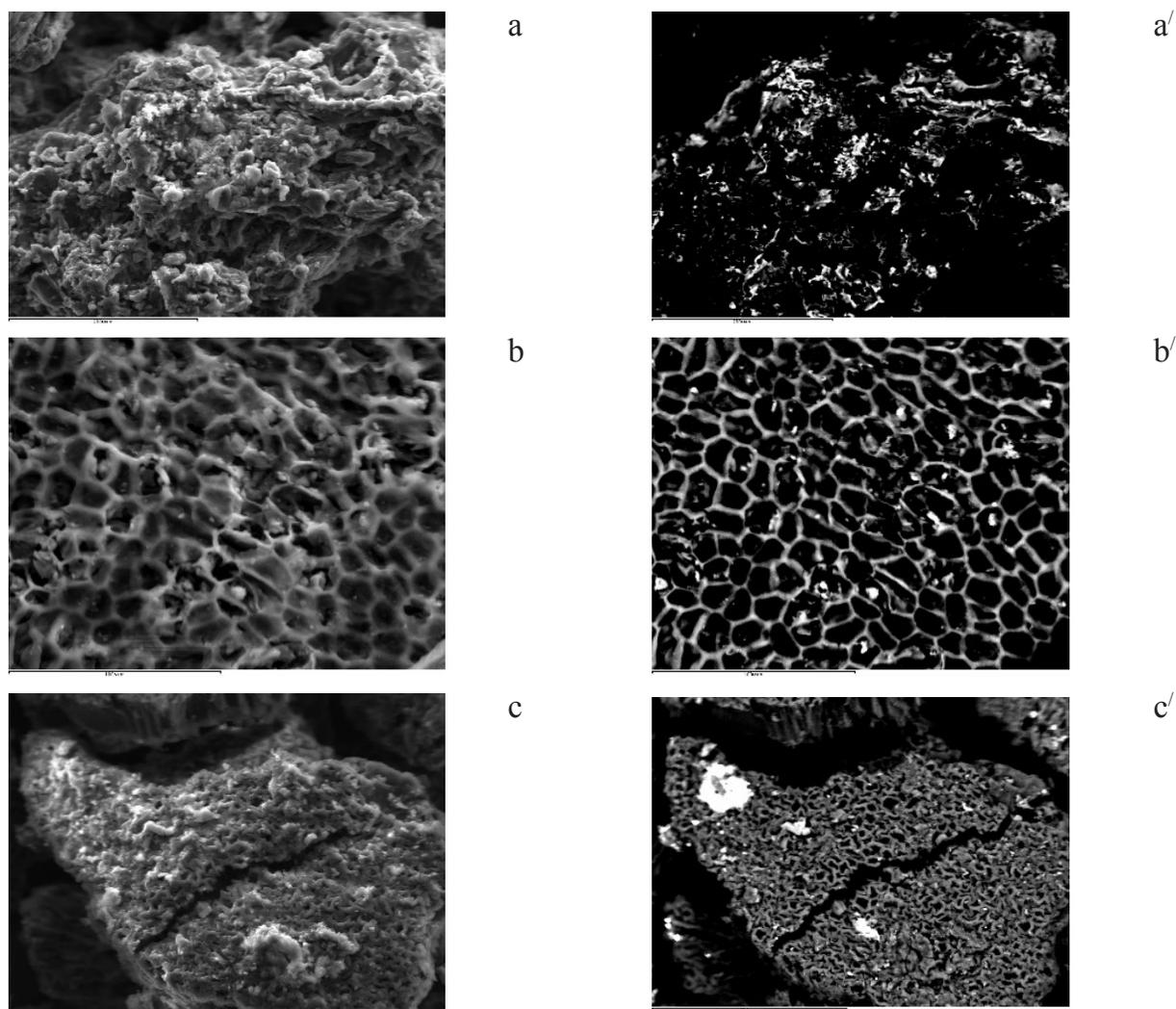


Fig. 5. Backscattered electron micrographs (a', b', c') and electron-beam-induced-current micrographs (a,b,c) of HL-PEI (a, a'), HL-PEPA (b, b') and HL-2-VP (c, c') lignin ion-exchangers with adsorbed rhenium ions.

the sorbents surface in presence of adsorbed rhenium ions allow estimating the perrhenate ions distribution in the polymeric phase (Fig. 5). The light sites on the SEM images correspond to areas of preferred rhenium ions concentrating.

The regeneration ability of the ion-exchangers has attracted great attention in the technology of rhenium extraction. It is one of the main criteria of their applicability in hydrometallurgical processes because the adsorbent should possess not only a high sorption capacity and selectivity but also high and stable regenerability for thousands of sorption/desorption cycles. Because of the higher sorption and kinetic properties of the lignin ion-exchangers when compared to those of

the commercial sorbents traditionally used in rhenium technology their regeneration properties are studied in dependence of various elution factors (the eluent's nature and concentration, the elution time, the number of the feasible sorption/desorption cycles).

As seen in Table 2, the desorption ability of the eluents decreases in the following order: $\text{H}_2\text{SO}_4 > \text{NaOH} \geq \text{NH}_4\text{OH} > \text{H}_3\text{PO}_4$. It is found that the sulfuric acid solutions are an efficient eluent of ReO_4^- ions, while the phosphoric acid solutions are the worst one. The increase of H_2SO_4 concentration leads to an increased metal desorption degree (Q, %). It is found that 2N H_2SO_4 is the optimum acid concentration for maximum rhenium recovery using lignin ion-exchangers. The regeneration

Table 2. Effect of nature and eluents' concentration on desorption degree of perrhenate ions ($t = 4$ days).

Ion-exchanger	Effect of different eluents on the Re desorption degree, %						
	0.5N H ₂ SO ₄	1N H ₂ SO ₄	2N H ₂ SO ₄	5N H ₂ SO ₄	1N H ₃ PO ₄	1N NaOH	10%NH ₄ OH
HL-PEI	35.56	60.12	76.71	77.15	55.95	64.81	64.81
HL-PEPA	18.89	34.16	61.38	61.38	20.08	42.26	32.00
HL-2-VP	2.17	4.55	10.77	10.77	5.85	21.54	10.77

properties of the ion-exchangers decrease with their basicity increase: HL-PEI > HL-PEPA > HL-2-VP. This means that the growing donor ability of the nitrogen atoms provides increased binding strength of the perrhenate ions. The best results referring to the trapped metal ions desorption are exhibited by the ion-exchangers of medium basicity based on PEI and PEPA containing primary, secondary and tertiary amine groups. The lignin ion-exchanger with 2-VP groups shows the lowest regeneration ability. The desorbed amount of Re on its surface is considerably smaller than the deposited one in contrast to the other sorbents. At repeated elution with 2N H₂SO₄, 1N NaOH and 10 % NH₄OH the desorption percentages are 7.59 %, 5.05 %, 5.15 % (PEI), 6.78 %, 2.20 %, 1.91 % (PEPA), 3.08 %, 1.15 %, 0.80 % (2-VP), respectively. The low content of desorbed metal ions in the second desorbate demonstrates the inexpediency of the repeated ions elution. These results testify that the chosen eluent volume (20 mL, a sorbent:solution ratio of 1:400) is sufficient for providing adequate perrhenate ions desorption, while the subsequent addition of the

same amount of the eluent does not lead to better results.

Fig. 6 shows that the major amount of the adsorbed metal ions is eluted from the polymer matrix of HL-PEI within the first 4 h with 2N H₂SO₄, while within 24 h when treating with 1N NaOH and 10 % NH₄OH. The duration of the rhenium desorption from HL-PEPA sorbent using these eluents is much higher than that from HL-PEI adsorbent. The desorption degree reaches values of 43 %, 35 % and 18 % within 4 h and 60 %, 42 %, 36 % within 24 h by elution with 2N H₂SO₄, 1N NaOH and 10 % NH₄OH, respectively. It is found that the alkaline and the ammonia solutions have the same metal desorption ability from HL-PEI ion-exchanger, but they are distinguished by the elution ability in respect to the ions adsorbed by HL-PEPA. This is probably caused by the higher basicity of HL-PEPA adsorbent in relation to which the ammonia solutions are a weak desorbent.

The cyclic sorption-desorption processes are studied under static conditions on HL-PEI and HL-PEPA lignin anion-exchangers using 2N H₂SO₄ and 10% NH₄OH as eluents (Table 3). The use of ammonia solutions is

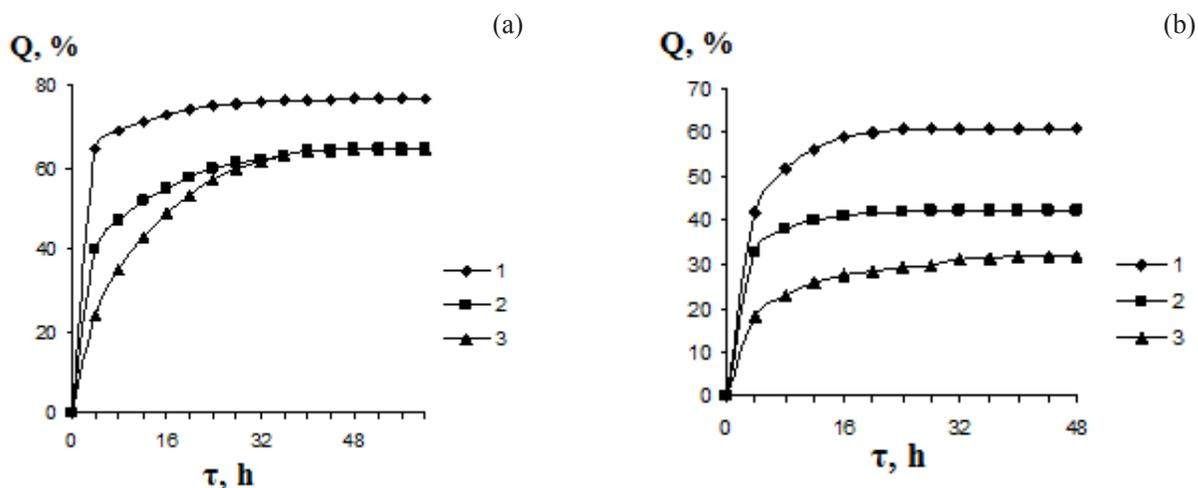


Fig. 6. Effect of the contact time on rhenium ions desorption with 2N H₂SO₄ (1), 1N NaOH (2) and 10% NH₄OH (3) from polymer matrix of HL-PEI (a) and HL-PEPA (b) ion-exchangers.

Table 3. Cyclic perrhenate ions sorption/desorption on lignin ion-exchangers under static conditions ($C_{Re} = 1.047$ g/L, Sorbent:Solution = 1:400).

Sorbent	Desorption conditions		Parameter	Number of sorption-desorption cycles									
	Eluent	τ , h		1	2	3	4	5	6	7	8	9	10
HL-PEI	2N H ₂ SO ₄	4	SC, mg/g	158.0	158.0	144.0	144.0	112.0	130.0	112.0	112.0	97.6	83.6
			R, %	37.7	37.7	34.4	34.4	26.7	31.0	26.7	26.7	23.3	20.0
			Q, %	76.7	56.0	44.7	67.2	93.6	70.2	86.8	93.6	80.3	93.8
	10% NH ₄ OH	24	SC, mg/g	158.0	158.0	144.0	112.0	51.2	51.2	83.6	83.6	65.2	65.2
			R, %	37.7	37.7	34.4	26.7	12.2	12.2	20.0	20.0	15.6	15.6
			Q, %	64.8	17.7	12.5	15.1	32.8	43.8	20.1	20.1	18.4	18.4
HL-PEPA	2N H ₂ SO ₄	4	SC, mg/g	144.0	144.0	144.0	112.0	83.6	83.6	83.6	51.2	83.6	65.2
			R, %	34.4	34.4	34.4	26.7	20.0	20.0	20.0	12.2	20.0	15.6
			Q, %	61.4	35.6	44.7	48.4	80.4	93.8	80.4	131.3	57.9	74.2
	10% NH ₄ OH	24	SC, mg/g	176.8	144.0	144.0	112.0	51.2	51.2	83.6	51.2	83.6	65.2
			R, %	42.2	34.4	34.4	26.7	12.2	12.2	20.0	12.2	20.0	15.6
			Q, %	31.7	9.7	2.5	10.8	23.4	23.4	14.4	2.3	14.4	18.4

R – sorption degree, %

determined by the possibility of rhenium ions extraction in the form of ammonium perrhenate, which is the main commercial product in rhenium production. Sulfuric acid is chosen due to its high elution ability.

The solution of 2N H₂SO₄ shows the best results for desorption of the metal ions trapped by HL-PEI ion-exchanger removing from 44.7 % to 93.8 % of the bonded rhenium for 10 sorption/desorption cycles. The sorbent loosening due to the periodic compression and expansion of the polymeric matrix during the cyclic sorption/regeneration processes causes probably increase of the elution degree, which in turn leads to an increase of the availability of the sterically blocked functional groups in the polymer phase. The data obtained testifies that the lignin ion-exchanger with PEI groups is the most suitable ion-exchanger for rhenium extraction. It possesses enhanced sorption and kinetic properties and can be regenerated by 2N H₂SO₄ solution within 10 sorption-desorption cycles without a significant loss of the metal adsorption capacity.

CONCLUSIONS

Ion-exchangers based on hydrolytic lignin of cotton husk possess better sorption and kinetic properties in relation to perrhenate ions in comparison with those of the well-known commercial Russian ion-exchangers AN-18, AN-21 and AV-18. These advantages are caused by the high concentration and availability of sorption active groups in the polymer matrix. It is found that the regeneration properties of the ion-exchangers depend on their basicity and decrease in the following order: HL-PEI > HL-PEPA > HL-2-VP. Of the four most commonly used eluents in rhenium technology, the order of effectiveness of rhenium ions elution is found to be H₂SO₄ > NaOH ≥ NH₄OH > H₃PO₄. The solution of 2N H₂SO₄ is more effective for rhenium desorption than the other eluents. It shows maximum metal recovery up to 76 % in case of HL-PEI ion-exchanger. The experiments on its cyclic reusing shows that it can be reused 10 times without a loss of efficacy, while 76 % of Re on the average is

recovered during the regeneration. The results suggest that this sorbent can be potentially useful for rhenium ions removal from sulfate solutions.

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