STUDY ON THE BEHAVIOR OF BIFUNCTIONAL ION EXCHANGER WITH HYDROXAMIC ACID AND AMIDOXIME GROUPS TO Cr(III) IONS SORPTION

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ABSTRACT

The sorption of Cr(III) ions on an acrylic ion exchange resin with functional groups of hydroxamic acid and amidoxime has been studied. In order to establish the proper conditions of sorption, the effect of some experimental factors (pH, initial concentration, amount of exchanger, contact time) on the retention process has been investigated. It was shown that the equilibrium distribution of Cr(III) between sorbent phase and solution is well described by the Langmuir model with two parameters. The analysis includes the presentation of the method used as well as the results of the procedures conducted in order to retain the metallic ions Cr(III) in comparison with the bifunctional acrylic resin. The procedures were conducted using the optical microscopy, SEM and XPS. The chemical analysis was conducted using the EDS procedure. The XPS and EDS analyses clearly showed the existence of chrome in the ions changer Cr(III). This aspect definitely demonstrates the special properties of the bifunctional acrylic resin.

The bifunctional resin under study exhibits favorable kinetic properties, indicating the flexibility of applications in environmental management.

Keywords: Langmuir model.,chelating sorbent, bifunctional acrilic resin,Cr(III) ion exchanger, preconcentration, separation, hydroxamic acid, amidoxime, IR, OM, SEM, XPS .

1. INTRODUCTION

Today, with the rapidly increasing urban population and water resources becoming more and more scarce, there is a strong need to reconsider our consumption patterns and the way we use our water resources. Developing countries suffer from water pollution; the high cost of contents and treatments make for major problems in these countries. A perspective method for water treatment is sorption. Using this method the sorbents have to answer to a number of requirements to be active, stable, selective, accessible, cheap and easy to regenerate /1/.

In order to find new materials fulfilling these requirements, a study concerning the sorption of Cr(III) ions from aqueous solutions on an acrylic ion exchange resin with hydroxamic acid and amidoxime functional groups has been performed /2/. The experimental results are very promising for removal of chrome(III) ions from aqueous effluents.

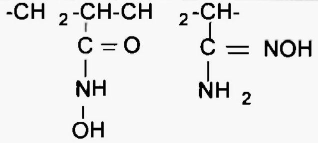
2. EXPERIMENTAL

2.1 Study of Cr(III) Ions Sorption on Bifunctional Acrylic Resin of Type A

- Acrylic bifunctional ion exchange of type A, with features recorded in Table 1 /3, 4, 5/.

Table 1

The features of acrylic bifunctional resin under study

Functional groups*	Weak acid exchange capacity		Diameter of particles (mm)
	mEq/mL	mEq/g	
 $\text{-CH}_2\text{-}\underset{\begin{array}{c}\vert\\ \text{C}=\text{O}\\ \vert\\ \text{NH}\\ \vert\\ \text{OH}\end{array}}{\text{CH}}\text{-CH}_2\text{-}\underset{\begin{array}{c}\vert\\ \text{C}=\text{NOH}\\ \vert\\ \text{NH}_2\end{array}}{\text{CH}}\text{-}$	1.38	4.06	0.3 – 0.8

2.1.1. Reagents, methodology

The ion exchanger was performed with a crosslinked degree of 10 % DVB in the presence of benzene, as diluent at dilution D = 0.25 (D = mL diluent/ mL diluent + mL conomers).

- Stock solution of Cr(III) with 5×10^{-2}M concentration,
- Working solutions, obtained by appropriate dilutions of the stock solution
- Buffer solutions of pH (CH_3COOH-CH_3COONa; NH_4Cl-NH_4OH)

The study of Cr(III) retention on the acrylic bifunctional resin was carried out by the batch method. Samples of about 0.05g exchanger were equilibrated with volumes of 25 mL solution containing known amounts of Cr(III). The phases were separated by filtration, after a determined time of contact (24 hours, intermittent stirring) The Cr(III) amount in filtrate was determined spectrophotometrically with complexon III (concentration range: 10-40μg/mL; λ= 550nm).

In order to establish the optimum conditions of Cr(III) retention, the influences of pH, initial concentration, amount of exchanger and contact time on sorption efficiency have been studied.

2.1.2. Initial pH influence

Due to the acid-base character of the both functional groups, the retention process of Cr(III) on acrylic bifunctional resin depends on the solution pH. Figure 1 presents the sorption percentage change as function of medium pH, adjusted by buffer solution addition /6/.

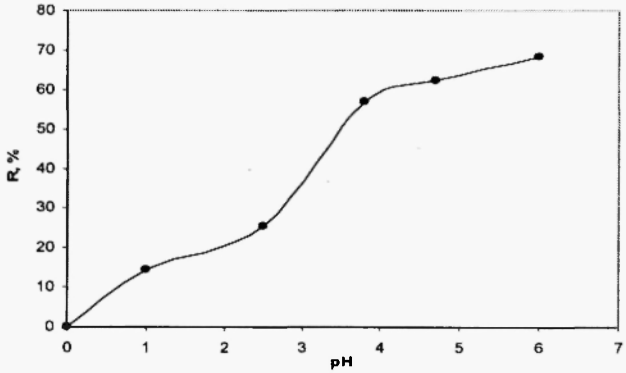


Fig. 1: Cr (III) sorption percentage as function of solution pH; C_0 = 156μg / mL; equilibration time of 24 hours.

As can be seen from Figure 1, the sorption process has high values in the pH range of 4-6. Up to the value of pH= 3, the metallic ion retention is very low, due to amidoxime group protonation resulting in the decrease of the weakly acid functional group toward H^+ ions. We should mention that the pH value corresponds to the solution obtained by a simple dilution of the initial solution, without use of buffer solution. For this reason, the subsequent determinations were performed in unbuffered solution.

2.1.3. Influence of Cr(III) concentration in initial solution

The effect of solution initial concentration on Cr(III) sorption by bifunctional acrylic resin is shown in Figure 2.

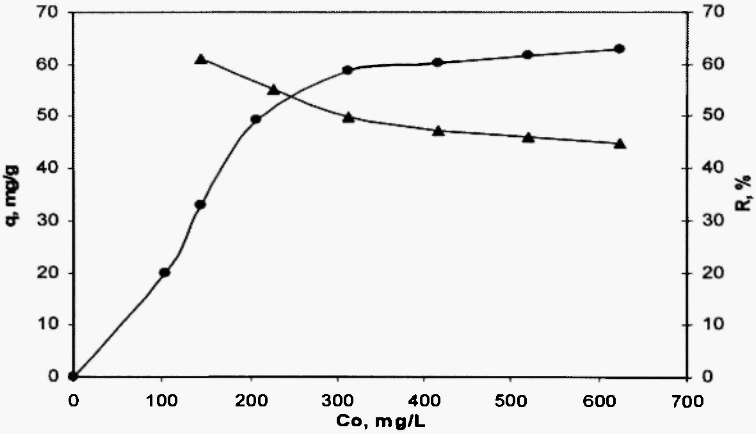


Fig. 2: Influence of initial concentration on Cr (III) retention by the ion exchange resin with hydroxamic and amidoxime resin (●) q, mg / g; (▲) R%, pH =4; time of 24 hours.

In solutions with pH=4 the amount of Cr(III) retained on acrylic bifunctional resin with functional groups of hidroxamic acid and amidoxime increases to metallic ion initial concentration increasing until to saturation of resin. On the other hand, the increase of Cr(III) results in the decrease of the sorption percentage. This behavior of the solid support suggests that the bifunctional resin could be efficient in quantitative recovery of Cr(III) from diluted solutions.

2.1.4. Influence of phase contact time

To point out the effect of phases contact time on Cr(III) retention process by acrylic bifunctional resin the experimental determinations were performed at two metallic ion initial concentrations: 156mg/L and 312mg/L respectively (Figure 3).

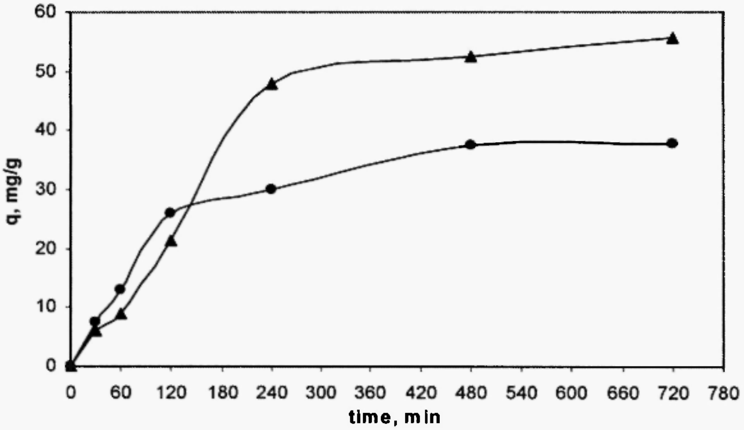


Fig. 3: The effect of phase contact time (●) 156 mg / L; (▲) 312 mg /L; pH = 4; 0.05 g of sorbent.

As can be seen, for Cr(III) a concentration of 156mg/L, almost the amount of metallic ion, is retained after about two hours. From solutions of higher Cr(III) concentrations the equilibrium is reached slowly, four hours being necessary for the entire amount of Cr(III) retention by the sorbent under study.

The value of the rate constant, K' (min^{-1}) has been calculated by processing the experimental data on the basis of Lagergren's equation /7/ (Table 2).

Generally, the kinetic properties of sorbents are expressed by means of the relative rate of the sorption process. This parameter is characterized by half – exchange notion, being the time necessary for the achievement of an exchange degree equal to 0.5. By the experimental data processing and F = f (time) plotting, the following results have been obtained:

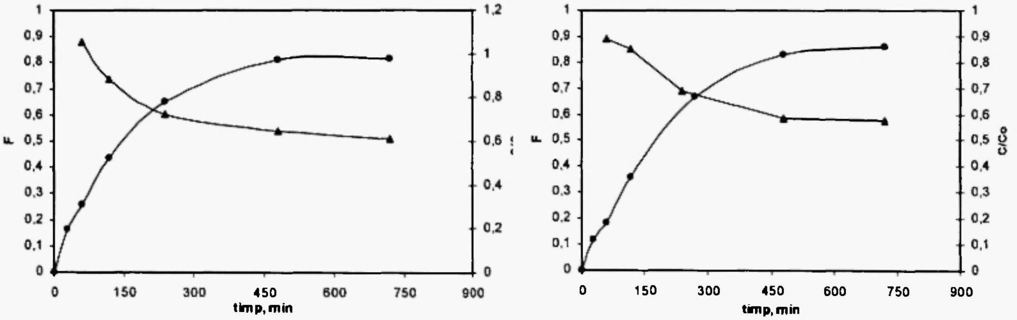
- for a concentration of 156 mg / L, $t_{0.5}$ = 2.5 hours (Figure 4 a);
- if the Cr(III) initial concentration is 312 mg / L, the $t_{0.5}$ value is 3.5 hours (Figure 4 b).

Table 2

Processing of experimental data according to Lagergren equation

	t, min	lg (q_0- q)	Equation of regression	R^2
156mg/L	30	1,48	y = -0,003x + 1,76	0,9977
	60	1,47	q_0 = 38,48	
	120	1,26	K'= 6,9x10^{-3}min^{-1}	
	240	0,99		
	480	0,31		
	720	-0,52		
	t, min	lg (q_0- q)	Equation of regression	R^2
312mg/L	30	1,71	y = -0,0018x + 1,7903	0,9963
	60	1,69	q_0= 58,87	
	120	1,57	K'= 4,14x10^{-3}min^{-1}	
	240	1,34		
	480	0,98		
	720	0,43		

The kinetic data lead to the conclusion that the Cr (III) retention on the acrylic ion exchange resin with hydroxamic and amidoxime groups is a process of mass transfer. Also, the kinetic data are in good agreement with the finding that the resin under study can be used to Cr (III) concentration from diluted solutions.



a b

Fig. 4: Half – exchange time determination (.) and C/C_0– f (time) dependence (▲) (a) - 156 mg / L; (b) – 312 mg / L.

2.1.5. Influence of sorbent dose

Another parameter under study has been the variation of the ion exchanger amount taken up per a determination. The experiments were performed by contacting different amounts of resin with volumes of 25 mL solution containing 316mg / L at pH =4 (Figure 5).

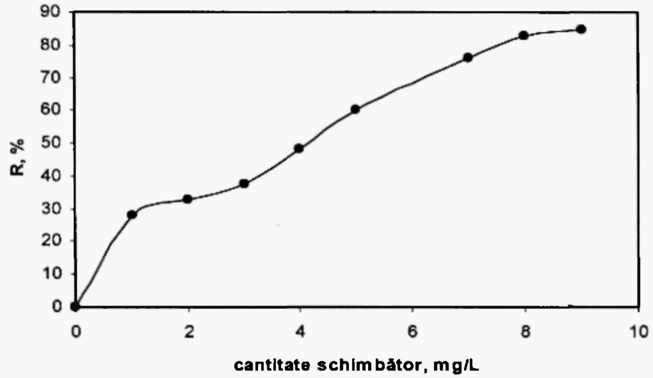


Fig. 5: The influence of the ion exchanger dose.

The dependence in Figure 5 points out an increase of the Cr (III) sorption percentage (R≈90%) as the ratio between resin amount and solution volume increases.

2.1.6. Characterization of the sorption process

The equilibrium distribution of Cr (III) ion between the ion exchange resin of type A and aqueous solutions of pH =4 and varied initial concentrations is plotted as the sorption isotherm (Figure 6a).

In order to perform sorption constants determination the experimental results were processed with the aid of linear equation and $C_e/ q = f(C_e)$ plot.

The retention of Cr (III) on the bifunctional acrylic ion exchange resin of type B has been tested under the same experimental conditions. The initial concentrations of the working solutions ranged between 104 to 624 mg / L, pH≈4, the contact time of samples being of 24 hours and exchanger amount of 0.05g. Figure 6b.shows the Cr (III) sorption isotherm that is nonlinear and also of the Langmuir type /8, 9/.

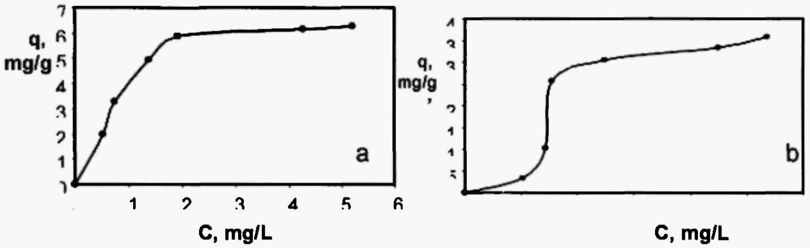


Fig. 6: The isotherm of Cr (III) sorption by the ion exchange resin with hydroxamic and amidoxime groups of type A (Fig. 6a) and type B (Fig. 6b)

In this case the experimental results were also processed according to the Langmuir linear equation for the determination of the sorption constants.

Moreover the experimental data have been processed by means of the Freundlich model The Freundlich isotherm characterizes the adsorption process from diluted solutions by an empirical equation of form: $q = K_F \cdot C^{1/n}$, where K_F and n are constants correlated to the surface area of adsorbent and the features of solute – adsorbant system, respectively

The Freundlich constants, K_F and n can be determined experimentally from the plot of Freundlich logarithmic equation: $\lg q = \lg K_F + (1/n) \lg 1/C$ /10/.

A favourable retention corresponds to $1 < n < 10$ condition. Figure 7 presents the Freundlich plots of the logarithmic equation for Cr (III) retention on the bifunctional acrylic resin of type A (a) and type B (b), respectively.

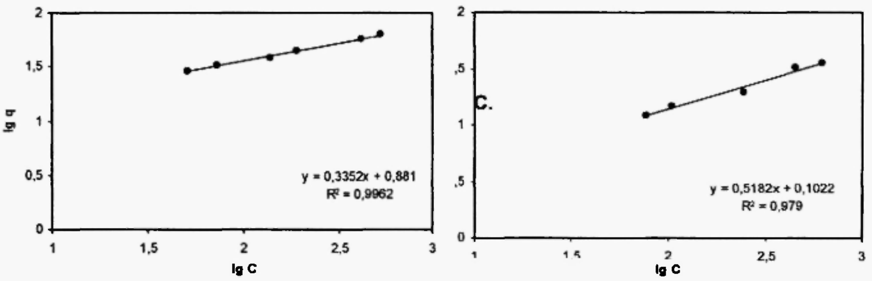


Fig. 7: Freundlich plots in Cr(III) – ion exchange resin of type A (a) and type B (b), with hydroxamic and amidoxime sorption systems.

By processing of experimental data the constants characteristic to Langmuir and Freundlich models have been derived. The obtained values together with the correlation coefficients, R^2, are given in Table.3.

Table 3

Processing of the data according to Langmuir and Freundlich models

		q_0(mg/g)	K_L(L/mole)	R^2
Langmuir model	Resin of type A	1.3842	699	0.9994
	Resin of type B	0.7961	547.40	0.9970
Freundlich model		K_F	n	R^2
	Resin of type A	7.8680	3.0175	0.9962
	Resin of type B	1.2653	1.9290	0.9790

The analysis of the data from Table 3 leads to the following findings:

- The values of correlation, R^2, indicate that the Cr(III) retention process on the acrylic bifunctional resin fitted better to the Langmuir model;
- The values of Langmuir constants, q_0 and K_L, derived from linear regression equation, point out the existence of a complexing mechanism between the metallic ions and the functional groups. Also it can be seen larger values of these parameters on the resin of type A, confirming the higher availability of this resin against Cr (III) ions.

On the basis of K_L sorption constant, the variation of apparent free energy (Gibbs) has been calculated, according to the equation: $\Delta G = - RT \ln K_L$, where R is the general constant of gases (8.31 J / mole) and T is the absolute temperature /11/.

The values of apparent Gibbs free energy determined for both types of ion exchange resin are: $\Delta G = - 15.948$ KJ/ mole for the resin of type A and $\Delta G = - 15.352$ KJ/ mole for the resin of type B, respectively.

The negative values of the apparent Gibbs free energies point out a very high affinity and availability of the acrylic ion exchange resin functional groups against Cr (III) ions.

The equilibrium parameter, K_R, has for the Cr (III) sorption process on the acrylic bifunctional resin of type A and B, the following characteristic values: K_R=0.4170 and K_R= 0.4770, respectively. The analysis of the obtained data lead to the conclusion that the Langmuir sorption isotherms are favourable to the retention process of Cr(III) ion on bead surface of ion exchanger.

A synthetically description of Cr (III) retention on bifunctional acrylic ion exchange resin of type A and B, in Table 4:

Table 4

Comparative experimental results

	Type A	Type B
The optimum range of pH for Cr(III) sorption	4 – 6	4 – 6
Cr(III) concentration in initial solution of pH =4	The amount of retained Cr(III) on initial solution increases increasing. The increase concentration amount results in the percentage decrease of metallic ion sorption	
Kinetic characterization of the sorption process by : - The constant of the sorption rate, K′ (min^{-1}) - Half – exchange time, $t_{0.5}$ (h)	156mg/L 312mg/L 6.9×10^{-3} 4.14×10^{-3} 2.5 3.5	
The amount of the ion exchange resin	The retention percentage increases up to 90% on increase of the ratio between the sorbent dose and solution volume.	
Sorption characterization by values of Langmuir constants: - q_0, mmole / g sorbent - q_0, mg / g sorbent - K_L L / mole	 1.3842 87.953 699	 0.7961 50.584 547.40
Variation of apparent Gibbs free energy, ΔG, KJ/mole	- 15.948	- 15.352
Characterization of the Cr(III) retention process by means of Freundlich isotherm : - K_F - n	 7.6860 3.0175	 1.2653 1.9290

The experimental results carried out on the type A and type B resins revealed that the type A resin has a superior behavior in the sorption process, compared to the type B resin.

Note:

The experimental determinations carried out on two types of resin revealed that the type A has a superior behavior in the sorption process, compared to the type B. Therefore, the investigation was continued only on the type A resin.

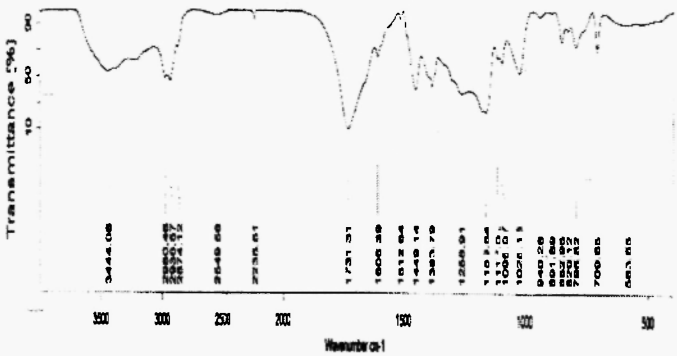
3. INVESTIGATIONS

3.1 Study of Metallic Ion Retention on the Bifunctional Acrylic Ion Exchange Resin by IR Spectroscopy

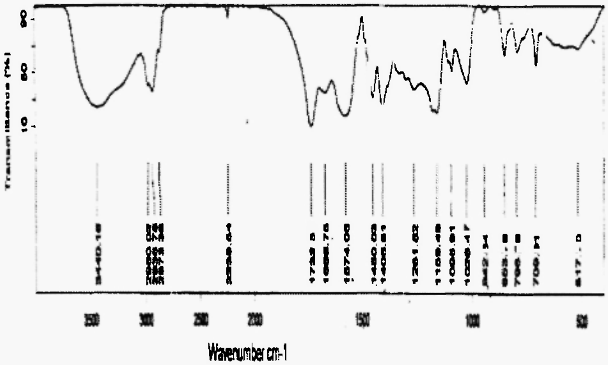
3.1.1. IR investigation

The study of molecular spectra IR can supply qualitative data of high utility concerning the sorption mechanism of metallic ions on solid matrices with complexing properties.

In the acrylic ion exchange resin with hydroxamic acid and amidoxime groups instance, the vibration spectra of the resin complexed with Cr(III) (Figure 8b) in comparison with uncomplexed spectrum (Figure 8a) have been studied /I 1/.The spectra were recorded to an IR spectrometer of FT – IR type, VERTEX 70.



(a)



(b)

Fig. 8: IR spectrum of the acrylic resin (a) before and (b) after (b) Cr(III) sorption

Starting with the research works carried out by the scientific team involved in the synthesis of this new type of resin, the identification of the absorption bands in the spectra of the samples under study has been carried out by comparison with the literature correlation tables (Table 5.)

3.1.2. Results and discussion

Analyzing the changes of vibration bands from IR spectra of the acrylic resin in metallic ion absence and presence, respectively, the following conclusions may be drawn:

- The broad band at 3440 cm^{-1} is attributed mainly to the group – OH which is present both in hydroxamic acid and amidoxime groups. The change of this band might be determined by hydroxyl group involvement in the bonding of metallic ions.
- The broadening of band with the frequency of 1732.37 cm^{-1} is pointed out in the retention of two instances of two metallic ions This band is attributed to the valence vibrations of the >C =O bond that is present in the hydroxamic acid group only.
- As can be seen, the vibration of – C =N – bond, characteristic to the amidoxime group, completely disappears in the case of the presence of metallic ions, leading to the conclusion this group is involved in Cr(III) bonding, too.
- Also, there are major changes of the bands from 1026 – 1200 cm^{-1}range,

due to the – C – N – bond that is present both in hydroxamic acid and amidoxime groups.

In this context of upper assertions, the metallic ions can form with both functional groups, hydroxamic acid and amidoxime , respectively, complex combinations of the following type:

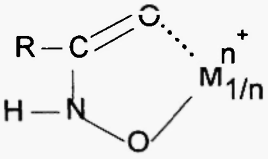


Table 5

The major spectral attributions of the absorption bands

Absorption bands (cm^{-1})		Group
Bifunctional acrylic resin	Acrylic Resin + Cr(III)	
3440 broad band	3444	- OH and – NH
1732.37 narrow band	1731.31 broad band	> C = O
1669.75 broad band	–	- C = N -
1620	–	- NH_2
1574.06 broad band	1605.39 very narrow band	= NH
1406.64 narrow band	1383.79 broad band	- CH_2
1026 – 1200 narrow bands	1025 – 1200 broad bands	- C – N
942.64	940.28	= N –O -

3.2. Optical microscopy investigations of Metallic Ions Retention on the Bifunctional Acrylic Resin

OMNIMET 3 optical microscopy equipment, made of BUEHLER Ltd., equipped with a NIKKON EPIPHOT digital photo-camera was performed.

3.2.1. Results and discussion

The two types of samples were enclosed onto a plasticine support. The transparent sample of reference (a) was investigated in the bright field (BF), the contrast being in comparison with the plasticine support. The milky background of the micrograph is due to this fact. The Cr(III) ions samples – samples (b) – were tested in dark field (DF).

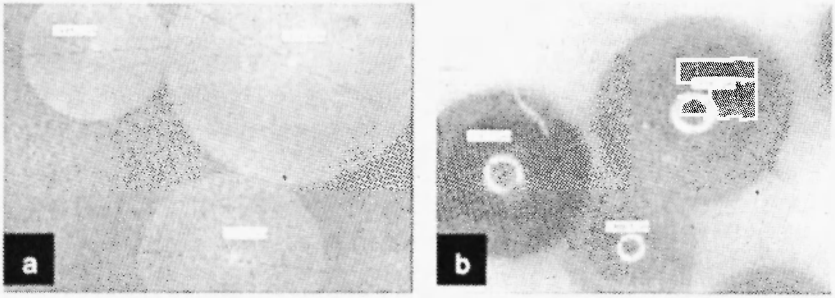


Fig. 9: Optical micrographs, x50

For all two types of samples the investigations point out a large enough dispersion spectrum of bead size ranging from 300 – 900μm, with a relatively regular micro-geometry, Figure 9

Note: The existence of a central bright point – at the reference sample – and central bright circle – at the samples Cr(III) – results from the optical effect of the operating bright field, BF and dark field, DF, respectively.

As can be seen, the micrographs indicate clearly the loading of exchanger beads with metallic ions.

3.3. XPS analysis

The analysis of elements and characterization of superficial layers has been performed by X–ray Photoelectron Spectroscopy, XPS (also known as ESCA, Electron Spectroscopy for Chemical Analysis). The used apparatus was a PHI 549 SAM/AES/XPS with ultra – high vacuum chamber (10^{-6} torr), equipped with double cylindrical mirror analyzer (DCMA) and X – ray primary source of high energy (12536 eV) of Mg - K_α type /13/.

After the general spectrum recording a scanning of high resolution was performed at the energy of 25 eV for C1s, Cr2p and O1s peaks. The positions of elements reported to the sharp binding energy C1s of the hydrocarbon side from carbon spectrum for the energy of 284.6 eV. The quantitative analysis is based on the empirical atomic factors of sensitivity from speciality literature. The results of two up–positioned XPS spectra are given in Figure 14; the plots are functions of type number of emitted photoelectrons as function of binding energy, N = f (binding energy), where "N" is the number of photoelectrons emitting at a given energy. Each peak corresponds to the emission characteristic of the analysed element.

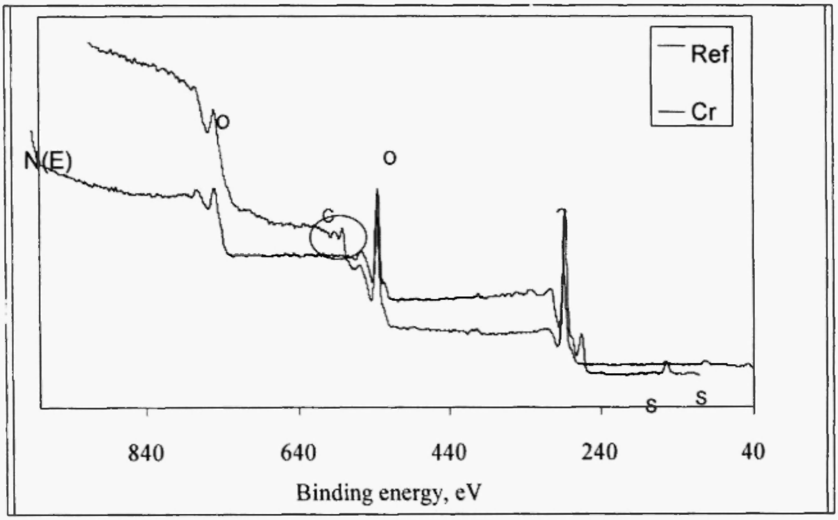
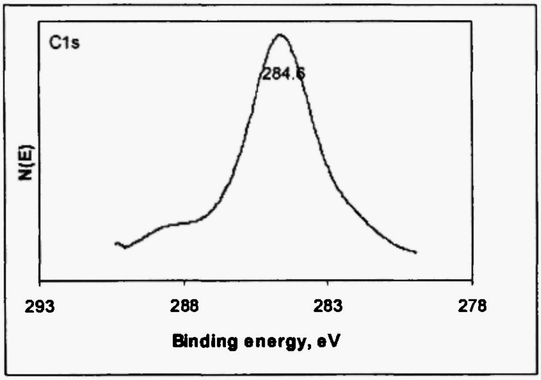


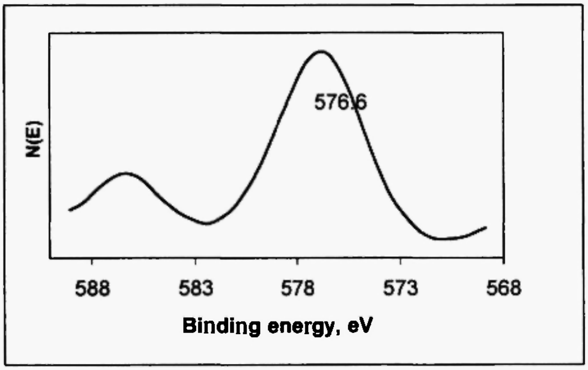
Fig. 10: The XPS general spectra obtained on the surface of analysed elements.

From spectra analysis the existence of carbon (binding energy = 284.6eV being energy of reference) chrome (binding energy = 576.6 eV) is obvious; also the peaks of oxygen and nitrogen existence can be noticed.

The interest peaks – C1s, Cr 2p – of the spectra from Figure 10 were performed at high resolution and are recorded in Figures.11



(a)



(b)

Fig. 11: High resolution XPS spectrum for the samples of Cr(III)
(a) – The peak for Cr(III) (b) – the peak for C

The reference sample high resolution XPS spectrum is identical with the C-peak from the Cr(III) sample, Fig. 11b.

The results of the XPS chemical analysis of samples surface are shown in Table 6

The existence of Cr(III) in samples with Cr(III) is noticed. The analysis of XPS high resolution spectra for three types of samples (with reference for carbon) lead to the conclusion that the most carbon has bond of C – C type, the binding energy being of 284.6 eV. Taking into account the positioning mode of peaks from XPS high resolution spectra for Cr(III) samples, it is obvious that the ions of Cr(III) are in the oxidized form, the binding energies being of 576.6 eV; the bond being of M^+ type.

Table 6

The surface chemical composition of the sample by XPS analysis

Sample	Content of elements, atomic percentage			
	C	O	N	Cr
Reference	70.6	19.4	2.1	0
Cr(III)	73.2	23.1	2.9	3..7

3. 4. SEM investigations

These samples were investigated using a JSM – 5600 Scanning Electron Microscope (SEM), equipped with an EDS / EDX analyzer for microanalyses.

Taking into account the fact that the samples are dielectric, a gold micro-coating of about 100Å thickness has been carried out over the samples in order to solve the question of the electric conductivity. The working parameters: 25 KV, nitrogen protecting atmosphere.

For both types of samples micrographs were performed – with magnifications of x200 and x10000, respectively – along with two chemical microanalyses, Figure 12.

The SEM micrographic investigations for the two samples point out the same type of morphology, without significant differences between the analyzed samples and the characteristic previously enunciated to the investigation by optical microscopy: an enough large dispersion spectrum of bead size, with a relative regular micro – geometry – Figure 12, The increment x10000 emphasizes the existence of bead porosity, the pores of nanometric magnitude.

The plots of chemical composition (Figure 12) resulting from data base are shown in Table 7.

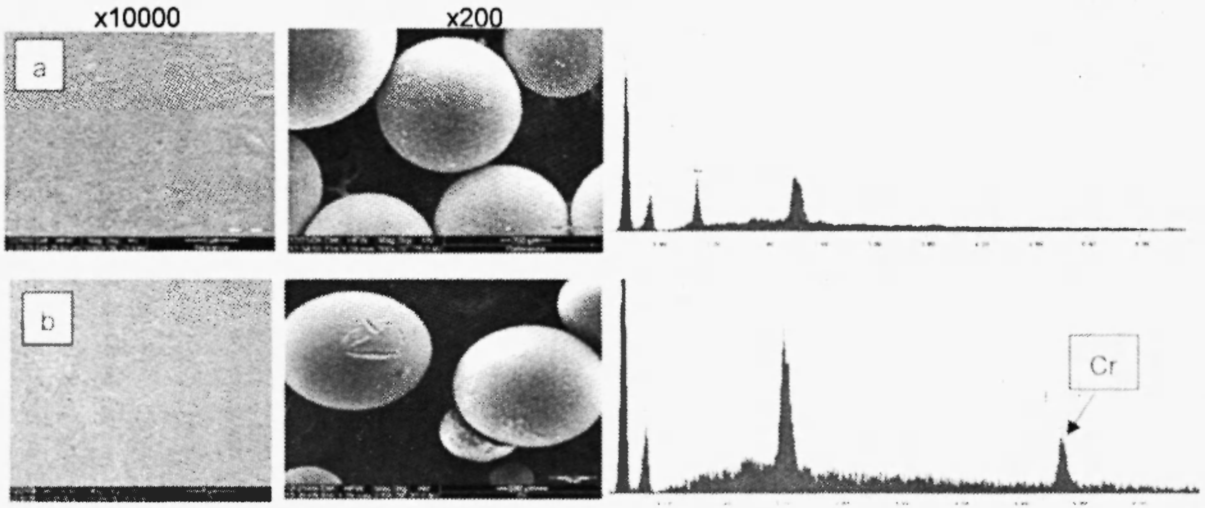


Fig. 12: SEM micrographs and chemical composition spectrum for the reference sample (a) and the Cr(III) sample (b).

Table 7

Chemical Composition of Samples by EDS analysis

		% weight	% atomic
Reference sample	C	69.85 – 70.80	77.38 – 78.25
	O	19.37 – 21.46	16.08 – 17.74
	Na	8.04 - 9.83	4.62 –5.68
Cr(III) sample	C	70.44 – 74.04	79.41 – 81.58
	O	20.34 – 22.16	16.90 – 18.62
	Cr	3.79 - 7.55	0.096 – 1.97

The existence is noticed of chrome on Cr(III) samples

Remarks:

- the peaks corresponding to gold from the plots of chemical analyses are due to the preliminary technological covering, reason for which it is mentioned;
- by comparing the values of samples chemical composition by XPS analysis and EDS analysis (Table 6 and 7) it is obvious an apparent non-concordance. This is due to the analysis principle: XPS analysis is a surface analysis (thin film distribution), while the EDS analysis supplies volumic information (tower distribution).

4. CONCLUSIONS

The researches carried out in order to establish a superior capitalization of the sorptive potential of new types of materials with uses in analytical separatology of high performance allowed us to reach the following general conclusions:

- The characterization of the acrylic bifunctional ion exchangers on the basis of total weakly basic capacity of exchange; a decrease in these capacity values (4.06 – 0.93 mequiv / g) can be seen as cross – linking degree increases ;
- The possibility of Cr(III) ion preconcentration by its sorption on the acrylic ion exchange resin with hydroxamic acid and amidoxime groups has been investigated.

- The optimum conditions of the Cr (III) retention process on the acrylic resin were established by monitoring the influence of some experimental factors, such as: pH, initial concentration, contact time, amount of sorbent.
- The acido–basic character of both functional groups incorporated into the acrylic resin influences the Cr(III) sorption process. For this reason, the solutions pH changes result in significant variation of the retention percentage.
- The increase of the amount of Cr (III) sorbed by resin on the initial solution concentration increasing suggests that the acrylic bifunctional ion exchange resin can be used to Cr (III) recovery from diluted solutions.
- The influence of phase contact time on the Cr (III) sorption process has been studied at two different concentration of metallic ion. This study leads to the finding that the time range for the sorption equilibrium achievement is shorter if the metallic ion concentration is lower. Thus, for a concentration of 156 mg Cr(III) /L, the largest part of the Cr(III) is retained after almost two hours ($t_{0.5}$=2.5 hours). On the other hand, in solutions containing 312 mg Cr(III) /L, the sorption equilibrium is reached after almost four hours ($t_{0.5} \approx 3.5$h)
- The kinetic data lead to the conclusion that the Cr(III) retention on acrylic ion exchange resin with hydroxamic acid and amidoxime is a mass transfer process, the diffusion of Cr(III) ions inside the exchanger beads being the rate–controlling step.
- The variation of exchanger amount used for a determination reflects the increase of Cr (III) sorption percentage (R≈90%) on the phase ratio increasing.
- The study of Cr(III) equilibrium distribution between the bifunctional acrylic resin of type A and B and the solutions of pH ≈4 has been made by modeling the experimental data according to Langmuir and Freundlich isotherm models.
- The obtained results point out the fact that the Cr(III) retention process is described better by the Langmuir model of monolayer sorption.
- The values of the Langmuir sorption constants (q_0=1.3842 mmole/L, K_L=699L/mole) for the type A exchanger and q_0= 0.7961mmole/L, K_L= 547.40L/mole for the type B exchanger) and Gibbs free energy (ΔG= - 15.948 KJ/ mole – for the type A exchanger and ΔG = - 15.352 KJ/ mole for the type B exchanger) suggest a high affinity of the functional groups

of the resin against Cr(III) ions and define a spontaneous process taking place by a complex mechanism.

- The analysis of these IR spectra reconfirmed the sorption mechanism by complexing.
- The XPS analysis and the EDS analysis revealed the existence of chrome in the ion changer Cr(III)
- Cr(III) was found in the oxidized and nonmetallic form.
- The binding energies are of 576.6 eV for the exchanger with Cr(III). The bond is of M^{n+} type.
- The carbon has bonds of C – C type, the binding energy binding being 284.6eV.
- The beads are porosive, the pores being of nanometric scale.

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