

ANOMALOUS SORPTION OF YTTRIUM IONS BY THE MUTUAL ACTIVATED HYDROGELS IN THE INTERPOLYMER SYSTEM OF POLY(METHACRYLIC ACID) AND POLY(4-VINYLPYRIDINE)

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Abstract. This paper considers the effect of mutual activation of poly(methacrylic acid) (PMAA) and poly(4-vinylpyridine) (P4VP) hydrogels during their remote interaction on the degree of yttrium ions sorption from an aqueous medium. Electrochemical properties were studied by conductometry and pH measurements to predict the activation possibility of these hydrogels. pH measurements showed that at 0.1 hour, the pH values were the lowest, indicating a high content of H⁺ ions in the aqueous solution. An increase in the interaction time to 24 hours leads to an increase in pH values, indicating a decrease in the content of H⁺ ions in the solution. The dependences of the specific electrical conductivity were studied. The experiments showed that the maximum values were observed at the ratios of 3 : 3 and 1 : 5 (gPMAA : gP4VP), which coincided with the result of pH measurements. The obtained results indicate the significant changes occurred in the electrochemical and conformational values of the initial macromolecules in the interpolymer system. Our research confirms the presence of remote interaction between hydrogels and their mutual activation.

Keywords: hydrogels, poly(methacrylic acid), poly(4-vinylpyridine), interpolymer systems, yttrium ions, sorption.

1. Introduction

Over the past decades, the need for rare earth elements (REE) has increased significantly, mainly because they are used as valuable components in advanced tech-

nologies.¹⁻³ However, the difference in ionic radii between neighboring REE is insignificant, so that the effective extraction of ions by the sorption method is a difficult task. Yttrium is currently mainly produced in some countries and does not meet consumers' needs, which indicates an insufficient volume of its production.

Polymer hydrogels are widely used in various fields of science, technology, and industry. The use of hydrogels in sorption processes is particularly relevant. It contributes to the fact that such polymers have a sorption capacity to metal ions.

A wide range of ion-exchange sorbents for the REE extraction is produced in large quantities annually.⁴⁻⁶ However, the conducted experiments showed a significant number of these sorbents are not widely used due to the low efficiency, selectivity, and sorption activity.

Polymer hydrogels with functional groups capable of binding metal ions are considered to be classified as highly selective structures of polymers. This leads to the fact that these polymers have the ability to sorbate metal ions, such as REE ions.

Non-ionic macromolecules that are unable to undergo ionization and subsequent dissociation do not participate in the remote interaction process, according to the principle of the remote interaction phenomena for polymer hydrogels in an aqueous medium. Therefore, the remote interaction of polymers with different structures leads to their functionalization.

Previous experiments have shown that polymer hydrogels' remote interaction results in a substantial improvement in their electrochemical and conformation characteristics. Functional groups without counter-ions, stabilized by intramolecular interactions, are formed as a result of remote interaction; electrochemical and conformational changes in macromolecules contribute to a substantial improvement in the intergel system's sorption capacity, consisting of two hydrogels; under such circumstances, the "long-range effect" results in high selectivity in relation to yttrium ions.

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Yttrium is the first element of the yttrium group. It is interesting to study the physicochemical sorption extraction of yttrium ions for predicting the properties of the remaining element groups. Therefore, the goal of developing methods for the selective extraction of REE is currently urgent. In this regard, this research's goal was to use an intergel system consisting of hydrogels of polyacrylic acid and poly-4-vinylpyridine in relation to yttrium ions to study the sorption potential and to predict the probability of using them for the extraction of other rare and rare earth metals.

2. Experimental

A MARK 603 conductometer and a Metrohm 827 pH-Lab (Switzerland) pH meter were used to measure electrical conductivity and pH of the solutions. The mass of swollen hydrogel samples for subsequent calculation of the degree of swelling (α) was determined by weighing on an electronic analytical SHIMADZU AY220 balance (Japan).

2.1. Materials

Polymethacrylic acid (gPMAA) was used as a polyacid in the interpolymer system, and poly-4-vinylpyridine (gP4VP) was used as a polybase. Hydrogels of poly(methacrylic acids) and poly(4-vinylpyridine) were synthesized in the presence of the crosslinking agent (N,N-methylene bisacrylamide), and the redox system $K_2S_2O_8-Na_2S_2O_3$ at 338-343 K. The degree of swelling of the synthesized hydrogels was α (gPMAA) = 27.73 g/g and α (gP4VP) = 22.97 g/g. Poly(4-vinylpyridine) (Sigma-Aldrich), crosslinked by divinylbenzene, was used in our experiments. The synthesized hydrogels in the aqueous medium formed an intergel pair of poly(methacrylic acid) hydrogel and poly(4-vinylpyridine) hydrogel (gPMAA: gP4VP). The experiments were carried out in a solution of yttrium(III) nitrate hexahydrate ($Y(NO_3)_3 \cdot 6H_2O$) with the concentration of 100 mg/L. The electrical conductivity and pH of the liquid during the sorption were measured at room temperature.

2.2. Electrochemical investigations

Research of the interpolymer system was conducted in the following order: each hydrogel in the dry initial state was placed in a cell made of polypropylene mesh, and then was moved in a glass with distilled water for sorption. Next, pH and electrical conductivity were measured in time (the pores of the filters from the grid were permeable to low-molecular-weight ions); then each hydrogel in the dry initial state was placed in a special grid, and then it was placed in a glass with a solution of

yttrium nitrate. The electrical conductivity and pH of the solutions were measured in the presence of hydrogels, with a further selection of aliquots.

2.3. Determination of Hydrogels

Swelling

Swelling coefficient was calculated by Eq. (1)

$$K_{sw} = (m_2 - m_1) / m_1 \quad (1)$$

where m_1 and m_2 are masses of dry and swelled hydrogels, respectively, g.

2.4. The Methodology of Yttrium

Ions Determination

The method for determining yttrium ions in the solution is based on the formation of a colored complex compound of the organic analytical reagent (Arsenazo III) with rare earth metal ions; the concentration of yttrium ions was calculated using a KFK-3M spectrophotometer.^{3,7-10} The degree of extraction (sorption) was calculated by the following formula:

$$\eta = ((C_{initial} - C_{residual}) / C_{initial}) \cdot 100 \% \quad (2)$$

where $C_{initial}$ is the initial concentration of metal in the solution, g/L. $C_{residual}$ is the residual concentration of metal in the solution, g/L.

2.5. Method for Calculating the Increase in the Degree of Extraction of Yttrium Ions with Activated Hydrogels and with Non-Activated Hydrogels

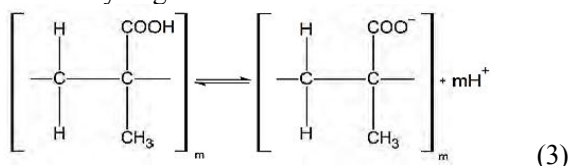
First, the degree of extraction per 1 mol of polyacid and polybase is determined based on the obtained data for the initial polymers in the ratios of 6 : 0 and 0 : 6 and at different values of the interaction time. The extraction rate per mole is multiplied by the number of moles of the polyacid or polybase at different ratios. Then, the degree of extraction of polyacids and polybases was summed up, and the total degree of extraction of non-activated hydrogels was obtained. Next, the extraction of activated and non-activated polymers was compared. The sum of the degree of extraction of non-activated hydrogels was taken as 100 % of activated hydrogels-x %. The sum of the recovery of non-activated hydrogels was subtracted from the degree of extraction of activated hydrogels.

3. Results and Discussion

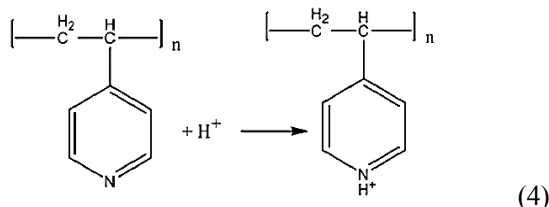
In this paper, the sorption of yttrium ions using an intergel (interpolymer) system was studied. Intergel systems are multicomponent systems consisting of two or more hydro- or organogels and a common solvent. Most

hydrogels belong to polyelectrolytes, which conformational behavior is highly influenced by the degree of ionization of macromolecular ball. The degree of ionization of each hydrogel in intergel systems is determined by the concentration of the second hydrogel. The specificity of the ionization process in intergel systems is the absence of a counter-ion in ionized groups, which is a consequence of remote interaction, the result of which is the mutual activation of hydrogels and the formation of uncompensated charges along the polymer chain according to the schemes (3) and (4). Two main reactions occur in the intergel systems:

1. Acid hydrogel dissociation:

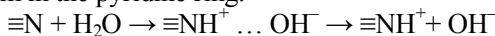


2. Binding of detached proton by nitrogen heteroatom:

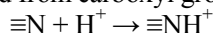


Dissociation occurs stepwise: firstly, there is ionization with ionic pair's formation, after that ionic pairs partially dissociate to separate ions.

Ionization and partial dissociation of nitrogen heteroatom in the pyridine ring:



Interaction of nitrogen heteroatom with proton, which was detached from carboxyl group:



Water molecules formation by interaction of H^+ and OH^- ions formed after functional groups reaction with water molecules:



Typically, reactions (3) and (4) do not break up the electric neutrality of a system, but in our case, the reaction (3) takes place in the volume of one specimen, and the other occurs in the volume of the sample, which is placed at the relatively long distance. Generated hydrogen ions in the volume of the first sample are chemically bonded by neighboring specimen. In other words, poly(methacrylic acid) gel (reaction 3) may be considered as a donor, and the second gel as an acceptor of protons (reaction 4).¹¹

Previous studies have shown^{1,11,12} that almost all intergel systems based on acidic (polyacrylic and polymethacrylic acids, etc.) and basic (poly(4-vinylpyridine) and poly-2-methyl-5-vinylpyridine, etc.) rare-crosslinked polymer hydrogels exhibit higher activity than their initial

components and lead to a significant change in the electrochemical, conformational and volume-gravimetric properties of the initial polymers. Moreover, it was found that the ratios of polymers, at which high ion sorption is manifested, differ significantly depending on the nature of acidic and basic hydrogels and the nature of rare earth metals.

These results were obtained by studying the sorption of lanthanum, cerium, neodymium, scandium, and erbium ions by intergel systems. The influence of the state of the initial hydrogels on the sorption process was also revealed.

In this study, selective intergel systems based on PMAA and P4VP in relation to yttrium ions were determined. The studied hydrogels differ in that the functional groups in the components of intergel systems are located on different polymers. The activation process of the gPMAA:gP4VP intergel system was studied, in which the specific electrical conductivity, pH of aqueous solutions, and the abnormal sorption of yttrium ions were measured. The concentrations of these hydrogels (gPMAA:gP4VP) were $7 \cdot 10^{-3}$ mol/L and $1 \cdot 10^{-3}$ mol/L, $9 \cdot 10^{-3}$ mol/L, and $7 \cdot 10^{-3}$ mol/L in ratios of 5 : 1 and 1 : 5, respectively. The features of the interaction of two hydrogels in the presence of yttrium nitrate direct contact are studied by the authors and described in detail in the figure and graphs.¹³⁻¹⁸

Fig. 1a shows changes in the specific electrical conductivity of the aqueous medium in the presence of two hydrogels gPMAA:gP4VP and in the absence of contact between them. However, there are no picks at a ratio of 5 : 1 (PMAA: P4VP) and growth at ratios of 3 : 3 and 1 : 5, depending on the specific electrical conductivity, this is due to an increase in the content of OH^- groups in the aquatic environment since from the pH data PMAA-P4VP the concentration of hydrogen decreases at these ratios. This is possible in the case of detachment of the OH^- group during the destruction of the inter-chain interaction with H^+ ions. The increase in specific electrical conductivity was observed only at the initial stage in the initial hydrogel P4VP and intergel systems. Further growth up to 24 hours is not intense.

In Fig. 1b, the dependence of the concentration of hydrogen ions on time in the presence of the intergel system gPMAA : gP4VP is shown. Fig. 1b characterizes the change in pH from the initial ratio at different times of interaction and the absence of direct contact between hydrogels. As can be seen from Fig. 1b, the dependence of electrical conductivity does not change rectilinearly depending on pH of gPMAA : gP4VP; there are significant peaks in the pH value of the number of indications for the interaction of components over a distance. The pH values are the lowest at 0.1 hour, indicating a high content of ions H^+ in the aqueous medium. Increasing the interaction time to 24 hours leads to an increase in the pH value, indicating

a decrease in the content of H^+ ions in water. pH peaks are observed at the ratio of gPMAA : gP4VP 5 : 1, 3 : 1, and 1 : 5. As the interaction time increases, the peaks over time smooth out and disappear. These maximum values indicate a significant decrease in the hydrogen concentration at these hydrogel ratios. A decline in the hydrogen concentration, in this case, indicates the interaction of the

polybase split off by remote interaction $-COOH$ of the PMAA group with the $-OH$ group or $\geq N$ nitrogen anion. Comparison of pH and specific electrical conductivity dependencies on gPMAA : gP4VP shows that the maximum values of specific electrical conductivity at ratios of 3 : 3 and 1 : 5 (gPMAA : gP4VP) coincides with the pH-dependent ratio of the components.

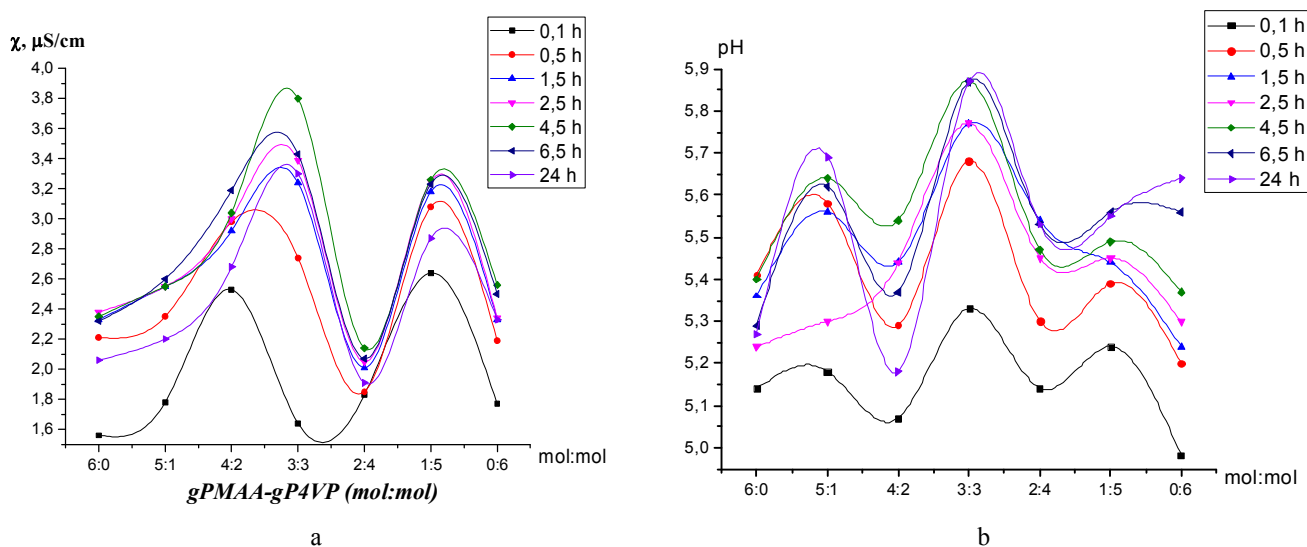


Fig. 1. Dependence of specific electric conductivity (a) and pH of water solutions (b) on gPMAA and gP4VP hydrogels molar ratios on time (h)

Table 1. Yttrium content in the aqueous medium after sorption by the gPMAA : gP4VP intergel system vs. time (measurement error $\pm 0.05-0.15$ %)

| τ , hour | $\eta(Y)$, % | | | | | | | | |
|---------------|---------------|-------|-------|-------|-------|-------|-------|-------|-------|
| | ratio | 0.1 | 0.5 | 1 | 1.5 | 2.5 | 4.5 | 7.5 | 24 |
| 6 : 0 | | 16.35 | 17.62 | 18.88 | 16.04 | 17.49 | 13.15 | 27.62 | 21.83 |
| 5 : 1 | | 13.81 | 16.34 | 10.01 | 17.36 | 11.7 | 21.83 | 20.30 | 27.62 |
| 4 : 2 | | 12.54 | 16.34 | 26.49 | 0.33 | 24.73 | 13.15 | 0.12 | 24.73 |
| 3 : 3 | | 23.95 | 18.88 | 27.76 | 7.36 | 7.36 | 5.91 | 17.20 | 24.73 |
| 2 : 4 | | 17.62 | 17.61 | 26.49 | 17.49 | 16.05 | 11.7 | 16.04 | 21.84 |
| 1 : 5 | | 13.81 | 0.17 | 17.61 | 1.57 | 4.46 | 5.91 | 11.7 | 11.70 |
| 0 : 6 | | 12.54 | 13.81 | 16.35 | 1.57 | 0.13 | 5.9 | 0.13 | 0.33 |

Table 1 shows the results of the sorption of yttrium ions by initial hydrogels (ratios 6 : 0 and 0 : 6), and the interpolymer system PMAA : P4VP at the ratio of 5 : 1 : 1 : 5 (gPMAA-gP4VP). After electrochemical studies, the process of sorption of yttrium ions from an yttrium nitrate aqueous solution with a concentration of $C(Y(NO_3)_3 \cdot 6H_2O) = 100$ mg/L) was considered. As can be seen from Table 1, the highest sorption activity concerning Y^{3+} ions showed the PMAA : P4VP hydrogel interpolymer system. The maximum content of yttrium ions in the aqueous medium after sorption was observed at ratios

of 3 : 3 and 2 : 4 and the duration of remote interaction was 1 hour. The content of the yttrium in the aqueous medium after sorption was 27.76 mol. % and 26.49 mol. %, respectively. Data on the residual concentration of yttrium ions exceed the degree of sorption by individual hydrogels of poly(methacrylic acid) and poly(4-vinylpyridine), which have values of 72.24 mol. % and 73.51 mol. %, respectively.

Fig. 2 and Table 2 show the dependence of yttrium ion extraction on molar ratios overtime during their sorption by the gPMAA : gP4VP interpolymer system. As can

be seen, the nature of sorption changes significantly with time. The maximum abnormal sorption of yttrium ions occurs at the ratio $gPMAA : gP4VP = 4 : 2$ at 1.5 h of remote interaction. At the same time, 99.88 mol. % of the yttrium was extracted. This indicates that polymer hydrogels subjected to initial separate swelling, at this ratio, acquire the highest degree of ionization, leading to a significant increase in sorption capacity.

Table 3 shows the dependence of the polymer chain on the degree of binding (in relation to yttrium ions) of the $gPMAA-gP4VP$ interpolymer system on time. The maximum values of the degree of the polymer chain binding in the interpolymer system were observed after 1 hour and amounted to 8.16 % with the ratio $gPMAA : gP4VP$ equal to 3 : 3. The degree of binding of the polymer chain values of individual poly(methacrylic acid) and poly(4-vinyl-pyridine) hydrogels after 48 hours were 3.62 mol. % and 1.73 mol. %, respectively. A definite increase in the degree of binding of the polymer chain was achieved after 0.5 hour of sorption. A significant increase in the degree of binding of the polymer chain was observed at 7.5 and 24 hours; this is particularly noticeable at the aspect ratio of 5 : 1 and 3 : 3.

Table 4 shows the degree of extraction of activated hydrogels in the interpolymer system (experimental) and the total degree of extraction of non-activated (calculated)

hydrogels of PMAA and P4VP components of the interpolymer system on time. Activated hydrogels of poly (methacrylic acid) and poly(4-vinylpyridine) in the intergel system acquire the maximum degree 38.35 mol. % and the optimal conformation for sorption of Y^{3+} ions at their remote interaction, which leads to an abnormally high degree of sorption.

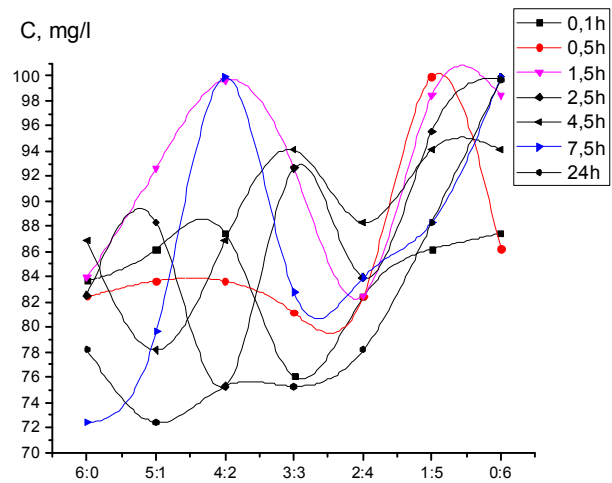


Fig. 2. Dependence of the degree of yttrium ions extraction by the ratios of $gPMAA : gP4VP$ on time

Table 2. The degree of extraction of yttrium ions by the intergel system $gPMAA : gP4VP$ (measurement error $\pm 0.05-0.15$ %)

| τ , hour ratio | $\eta(Y)$, % | | | | | | | |
|------------------------|---------------|-------|-------|-------|-------|-------|-------|-------|
| | 0.1 | 0.5 | 1 | 1.5 | 2.5 | 4.5 | 7.5 | 24 |
| 6 : 0 | 83.65 | 82.39 | 81.12 | 83.96 | 82.51 | 86.85 | 72.38 | 78.17 |
| 5 : 1 | 86.19 | 83.66 | 89.99 | 92.64 | 88.30 | 78.17 | 79.61 | 72.38 |
| 4 : 2 | 87.46 | 83.66 | 73.51 | 99.67 | 75.27 | 86.85 | 99.88 | 75.27 |
| 3 : 3 | 76.05 | 81.12 | 72.24 | 92.64 | 92.64 | 94.09 | 82.8 | 75.27 |
| 2 : 4 | 82.38 | 82.39 | 73.51 | 82.51 | 83.95 | 88.30 | 83.96 | 78.16 |
| 1 : 5 | 86.19 | 99.93 | 82.39 | 98.43 | 95.54 | 94.09 | 88.30 | 88.30 |
| 0 : 6 | 87.46 | 86.19 | 83.65 | 98.43 | 99.87 | 94.09 | 99.87 | 99.67 |

Table 3. Dependence of the polymer chain binding degree to yttrium ions on time by the $gPMAA : gP4VP$ interpolymer system (measurement error $\pm 0.05-0.15$ %)

| τ , hour ratio | Binding degree, % | | | | | | | |
|------------------------|-------------------|------|------|------|------|------|------|------|
| | 0.1 | 0.5 | 1 | 1.5 | 2.5 | 4.5 | 7.5 | 24 |
| 6 : 0 | 2.61 | 2.89 | 3.04 | 2.61 | 2.89 | 2.17 | 4.49 | 3.62 |
| 5 : 1 | 2.24 | 2.69 | 1.64 | 2.84 | 1.94 | 3.66 | 3.41 | 4.63 |
| 4 : 2 | 2.15 | 2.76 | 4.62 | 0 | 4.22 | 2.27 | 0.02 | 4.28 |
| 3 : 3 | 7.11 | 5.52 | 8.16 | 2.18 | 2.18 | 1.74 | 5.09 | 7.31 |
| 2 : 4 | 3.79 | 3.78 | 5.69 | 3.76 | 3.45 | 3.44 | 2.51 | 4.68 |
| 1 : 5 | 2.24 | 0 | 2.96 | 0.25 | 0.26 | 0.75 | 1.94 | 3.58 |
| 0 : 6 | 1.84 | 2.04 | 2.42 | 0.23 | 0.02 | 0.87 | 0.01 | 1.73 |

Table 4. Dependence of the degree of extraction of activated and non-activated hydrogels in the interpolymer system gPMAA : gP4VP on time (measurement error ± 0.05 - 0.15 %)

| ratio \ τ , hour | 0.1 | 0.5 | 1 | 1.5 | 2.5 | 4.5 | 7.5 | 24 |
|---|-------|-------|-------|-------|-------|-------|-------|-------|
| gPMAA : gP4VP = 5 : 1 | | | | | | | | |
| Degree of extraction of activated hydrogels, % | 86.19 | 83.66 | 89.99 | 82.64 | 88.3 | 78.17 | 79.70 | 72.38 |
| The sum of the degree of extraction of non-activated hydrogels, % | 84.35 | 83.02 | 81.54 | 86.37 | 85.41 | 88.06 | 76.96 | 81.76 |
| Increase in the degree of recovery of activated hydrogels, % | 2.18 | 0.77 | 10.33 | – | 3.38 | – | 3.63 | – |
| gPMAA : gP4VP = 4 : 2 | | | | | | | | |
| Degree of extraction of activated hydrogels, % | 87.46 | 83.66 | 73.51 | 99.67 | 75.27 | 86.85 | 99.88 | 75.27 |
| The sum of the degree of extraction of non-activated hydrogels, % | 84.92 | 83.65 | 81.96 | 88.79 | 88.3 | 89.26 | 81.55 | 85.34 |
| Increase in the degree of recovery of activated hydrogels, % | 2.99 | 0.01 | – | 12.25 | – | – | 22.47 | – |
| gPMAA : gP4VP = 3 : 3 | | | | | | | | |
| Degree of extraction of activated hydrogels, % | 76.65 | 81.12 | 72.24 | 92.64 | 92.64 | 94.09 | 82.8 | 75.27 |
| The sum of the degree of extraction of non-activated hydrogels, % | 91.00 | 84.29 | 82.38 | 91.20 | 91.2 | 90.48 | 86.13 | 88.92 |
| Increase in the degree of recovery of activated hydrogels, % | – | – | – | 1.58 | 1.58 | 3.99 | – | – |
| gPMAA : gP4VP = 2 : 4 | | | | | | | | |
| Degree of extraction of activated hydrogels, % | 82.38 | 82.39 | 73.51 | 82.51 | 83.95 | 88.3 | 83.96 | 78.16 |
| The sum of the degree of extraction of non-activated hydrogels, % | 86.19 | 84.92 | 85.72 | 93.60 | 94.08 | 91.69 | 90.71 | 92.50 |
| Increase in the degree of recovery of activated hydrogels, % | – | – | – | – | – | – | – | – |
| gPMAA : gP4VP = 1 : 5 | | | | | | | | |
| Degree of extraction of activated hydrogels, % | 86.19 | 99.83 | 82.39 | 98.43 | 95.54 | 94.09 | 88.30 | 88.30 |
| The sum of the degree of extraction of non-activated hydrogels, % | 62.30 | 85.55 | 83.22 | 96.02 | 96.97 | 92.89 | 95.29 | 96.08 |
| Increase in the degree of recovery of activated hydrogels, % | 38.35 | 16.69 | – | 2.51 | – | 1.29 | – | – |

As can be seen from Table 4, the dependence of the activated and non-activated hydrogels gives the minimum value in the ratio of 5 : 1 at 0.1 and 0.5 hours and the highest value of 10.35 mol. % at 1 hour; further, the extraction of activated hydrogels decreases to 3.63 mol. %. At a ratio of 4 : 2 for the period of 0.1 and 0.5 hours, the minimum degree of extraction of activated and unactivated hydrogels were 2.99 mol. % and 0.01 mol. %, respectively. At this ratio, the maximum values of 22.47 mol. % were observed at 7.5 hours. At a ratio of 3 : 3 the degree of extraction of activated and non-activated hydrogels were 1.58 mol. % – 3.99 mol. % at 1.5, 2.5, and 4.5 hours. At ratios of 2 : 4, the increase in the degree of extraction of activated hydrogels compared to the sum of the degree of extraction of non-activated hydrogels is equal to zero. At a ratio of 1 : 5, the activity of the intergel system was observed. The maximum value

of the extraction degree of activated and non-activated hydrogels in the intergel system after 0.5 hour was 64 mol. % at a ratio of gPMAA : gP4VP = 5 : 1.

The obtained results on the sorption of yttrium ions, which are consistent with the results of an increase in pH, as can be seen from Fig. 1b, high pH values were observed at hydrogel ratios of 5 : 1, 3 : 3, and 1 : 5. Formation of charged COO^- and $\geq\text{NH}^+$ groups, which are more active as compared with the molecular state of molecular groups. The results of the sorption confirm that the maximum increase in the degree of yttrium extraction with hydrogels is observed at ratios 5 : 1 and 1 : 5. For example, the sum of the extraction degree reaches 10.33 mol. % at 1 hour of interaction at a ratio of 5 : 1, and 38.35 mol. % at a ratio of 1 : 5 at 0.1 hours of interaction.

4. Conclusions

The sorption of yttrium ions by an intergel system consisting of a weakly acidic hydrogel of polymethacrylic acid (gPMAA) containing functional acid carboxyl groups –COOH and a weakly basic hydrogel of poly(4-vinylpyridine) (gP4VP) was studied.

Some remote interaction features between hydrogels of poly(methacrylic acid) and poly(4-vinylpyridine) were studied. The lowest pH values at 0.1 hour indicated a high content of H⁺ ions in the aqueous medium. An increase in the interaction time to 24 hours leads to an increase in pH values, indicating a decrease in the content of H⁺ ions in the solution. At the same time, an increase in electrical conductivity was observed at ratios of 3 : 3 and 1 : 5 in the gPMAA : gP4VP interpolymer system.

The results of abnormal sorption confirm that the maximum increase in the degree of yttrium ions extraction by hydrogels was observed at the ratios of 4 : 2 and 1 : 5. For example, the sum of extraction rate reaches 99.88 mol. % and 99.93 mol. % at 4 : 2 at 7.5 hours of interaction and at a ratio of 1 : 5 at 0.5 h of an interaction time, respectively. Whereas, for the initial gPMAA, the sum of extraction rate was 72.38 mol. % and for gP4VP it was 86.19 mol. %.

The maximum increase in the degree of yttrium ions extraction was 22.47 mol. % at the ratio of gPMAA : gP4VP = 4 : 2 at 7.5 hours of interaction, and 38.35 mol. % at a ratio of 1 : 5 at an interaction time of 0.1 hours.

The content of the yttrium in the aqueous medium after sorption showed a maximum value in the ratios of 3 : 3 and 2 : 4 at 1 hour of the station interaction. At the same time, the content of the yttrium in the aqueous medium after sorption was 27.76 mol. % and 26.49 mol. %.

The obtained results indicate the possibility of developing an effective sorption technology for the extraction of yttrium ions from industrial solutions.

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АНОМАЛЬНА СОРБЦІЯ ІОНІВ ІТРИЮ ВЗАЄМНО АКТИВОВАНИМИ ГІДРОГЕЛЯМИ В ІНТЕРПОЛІМЕРНІЙ СИСТЕМІ ПОЛІ(МЕТАКРИЛОВОЇ КИСЛОТИ) ТА ПОЛІ(4-ВІНІЛПІРИДИНУ)

Анотація. У цій статті розглянуто вплив взаємної активації гідрогелів полі(метакрилової кислоти) (ПМАК) і полі(4-вінілпіридину) (П4ВП) під час їхньої дистанційної взаємодії на ступінь сорбції іонів ітрію з водного середовища. Електрохімічні властивості вивчали за допомогою кондуктометрії та вимірювання рН, щоб передбачити можливість активації цих гідрогелів. Вимірювання рН показали, що через 0,1 години значення рН були найнижчими, що вказує на високий вміст іонів H^+ у водному розчині. Збільшення часу взаємодії до 24 годин приводить до підвищення значень рН, що свідчить про зменшення вмісту іонів H^+ у розчині. Досліджено залежності питомої електропровідності. Експерименти показали, що максимальні значення спостерігали за співвідношення 3 : 3 та 1 : 5 (гПМАК : гП4ВП), що збіглося з результатом вимірювання рН. Отримані результати свідчать про суттєві зміни електрохімічних та конформаційних величин вихідних макромолекул інтерполімерної системи. Наші дослідження підтверджують наявність дистанційної взаємодії між гідрогелями та їхню взаємну активацію.

Ключові слова: гідрогелі, полі(метакрилова кислота), полі(4-вінілпіридин), інтерполімерні системи, іони ітрію, сорбція.