UDC: 661.183.12
DOI: https://doi.org/10.30546/2521-6341.2026.01.937

PROSPECTS FOR THE DEVELOPMENT OF RESEARCH IN THE FIELD OF DESIGNING EFFICIENT ION EXCHANGERS

Mizrobjon Khalim ugli ZARIPOV, Vokhid Nizomovich AKHMEDOV, Niginabonu Qobil qizi JAMILOVA

[1] *Assistant, Bukhara State Technical University,Bukhara, Republic of Uzbekistan*

[2] *Professor, Bukhara State Technical University,Bukhara, Republic of Uzbekistan*

[3] *Doctoral Candidate, Bukhara State Technical University,Bukhara, Republic of Uzbekistan*

ARTICLE INFO

Article history:
Received:2025-11-08
Received in revised form:2025-11-21
Accepted:2025-12-22
Available online:2026-06-26

Keywords: furfural, furan compounds, thiourea, phosphoric acid derivatives, polysilica acid, DAA, KOH, cations, oligo(polymer), molecular weight, vinylacetylene, sodium tripolyphosphate, IR spectrum, dimethylformamide, chromatography-mass spectrometry.

ABSTRACT

The article emphasizes the importance of using furfural, phosphoric acid, and thiourea as the main monomers in the synthesis of ion exchangers. Based on this approach, the synthesis of new ion-exchange polymers derived from furfural as a secondary raw material is presented, along with the study of their sorption and operational properties, determination of the molecular weight of the resulting ion exchanger, and a description of the method for its preparation. Identifying effective and practical applications of these materials for the treatment of industrial and purified waters in various chemical industry processes, including hydrometallurgy, holds significant scientific, technical, and practical importance.

1. INTRODUCTION

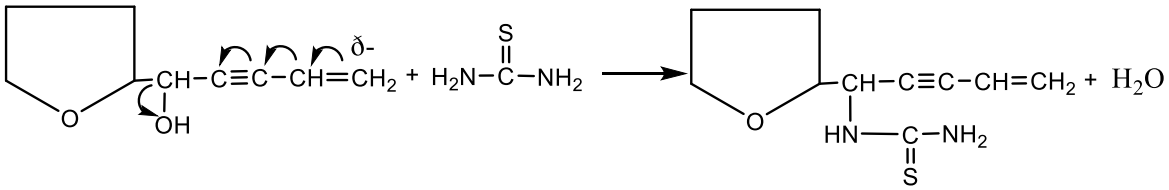
In recent years, the development of materials and compositions with desired properties containing phosphate groups has gained increasing importance. Phosphate-containing natural compounds are components of widely used medicinal pharmaceuticals. Compounds with phosphate groups form the foundation not only of inorganic chemistry but also of living organisms. The ease of modification of the phosphate group in organic compounds is of both practical and theoretical significance and has attracted considerable interest among researchers. At present, the scale of industrial organic synthesis is so large that the issue of limited natural oil and gas resources required to meet these demands remains relevant. In this context, the production of key compounds from naturally renewable raw materials is considered a promising direction [1-3].

Modern advances in science and technology have made it possible to create a new class of polymeric composite materials formed from a combination of components of different chemical nature, which significantly surpass the properties of the individual starting components. In terms of their overall composite characteristics, they exhibit distinctive physicomechanical, magnetic, and optoelectronic properties, as well as high chemical and thermal stability and enhanced resistance to various types of radiation. In recent years, furan derivatives have gained increasing importance in the development of materials and compositions with predetermined

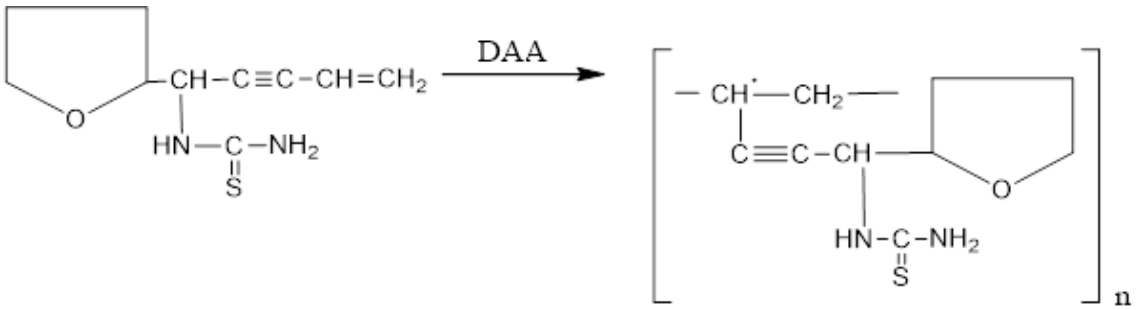
properties [4-6]. Inorganic sorbents, such as metal (IV) phosphates, are promising materials for the separation of various ions, particularly alkali metal cations that are difficult to isolate by other methods, as well as for deep purification [7]. These ion-exchange materials are characterized by high radiation resistance and the ability to sorb alkali metal cations, making them suitable for applications in the nuclear industry. The ability to selectively absorb a range of cations from a mixture containing a large number of competing ions is also of significant importance. To ensure good mixing of thiourea with the reaction medium and the formation of a homogeneous system, it was first dissolved in a small amount of hot ethanol [8-10]. Then, 1-(tetrahydrofuran-2-yl) pent-4-en-2-yn-1-ol was added dropwise using a separatory funnel. After achieving an equimolar ratio, a few drops of acid (e.g., 0.1 M HCl or H2SO4) were added to the mixture, and it was heated at 50–60 °C for 1–2 hours. As a result, a condensation reaction occurred, forming a C–N bond and releasing water, which could be observed visually. During the reaction, under the influence of these chemical interactions, 1-(1-(tetrahydrofuran-2-yl) pent-4-en-2-yn-1-yl) thiourea was obtained. [11-13].

2. EXPERIMENTAL PART

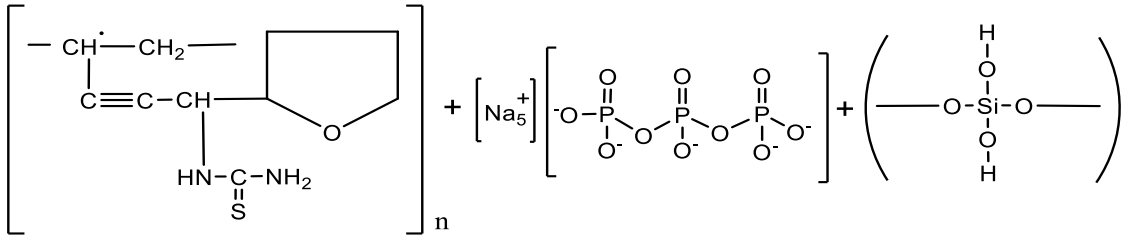
First, thiourea reacts with the hydroxyl group of the intermediate compound according to the following scheme.

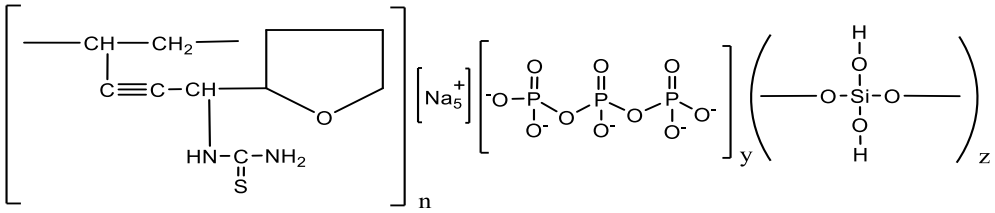


The resulting intermediate compound undergoes polymerization. The reaction proceeds in a single system following a specific sequence.



To increase the number of active centers and electron pairs in the polymer, as well as to ensure mechanical strength, sodium tripolyphosphate was used, and the process can generally be described as follows.





The process was carried out in the presence of an initiator. DAC was used as the initiator, which decomposes as follows, enabling the reaction to proceed. The pure polymer was isolated in dimethylformamide using the extraction method, and its physical properties were studied. The viscosity of polydivinylfurfuryl sodium tripolyphosphate (before the addition of polysilicic acid) was measured using a HAAKE Viscotester 2 Plus viscometer and can be represented in the following graph.

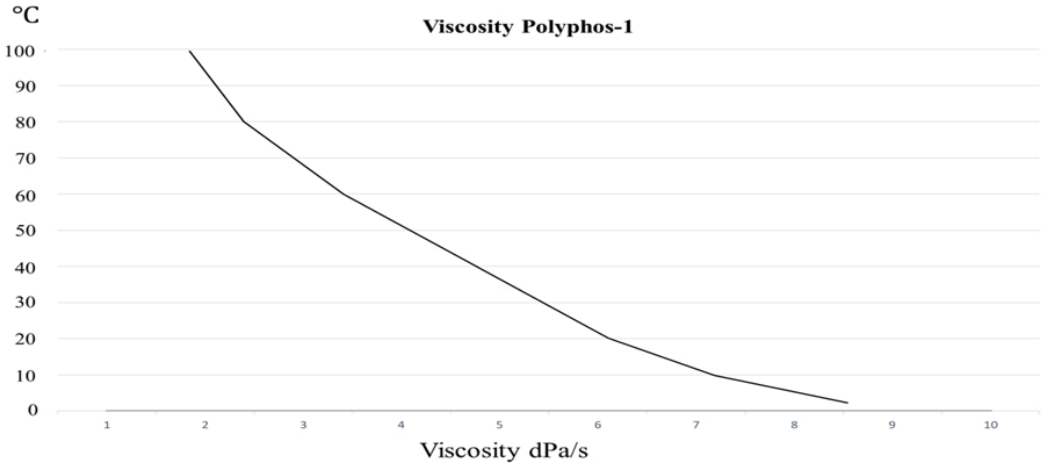


Fig. 1. *Change in viscosity of the reaction mixture.*

During the reaction, as the monomers combine, the molecular weight increases, and accordingly, the viscosity of the system rises. In the initial mixture, increasing the proportion of the monomer 1-(1-(tetrahydrofuran-2-yl) pent-4-en-2-yn-1-yl) thiourea leads to an increase in the molecular weight of the copolymers. This, in turn, is explained by the high reactivity of the vinyl group toward polymerization.

In the presence of a strongly alkaline system, the reaction time and product yield depend on the temperature, reaching up to 74 %. A range of modern physicochemical methods was used to identify the synthesized compounds. To characterize the bonds within the substances, IR spectroscopy was employed.

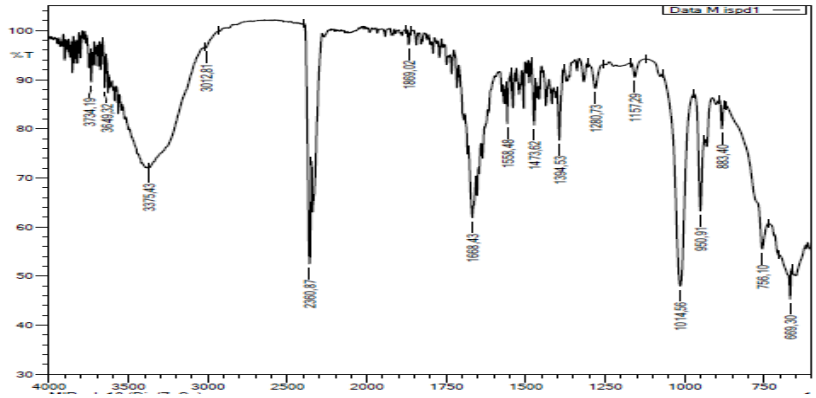
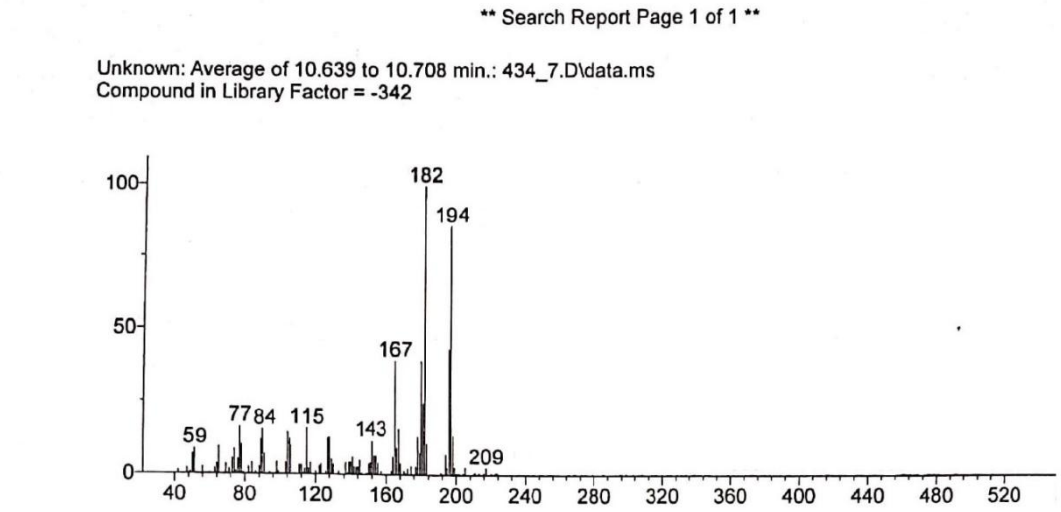
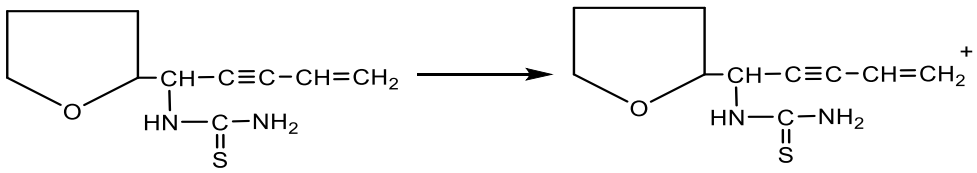


Fig. 2. *IR spectrum of the synthesized ion exchanger.*

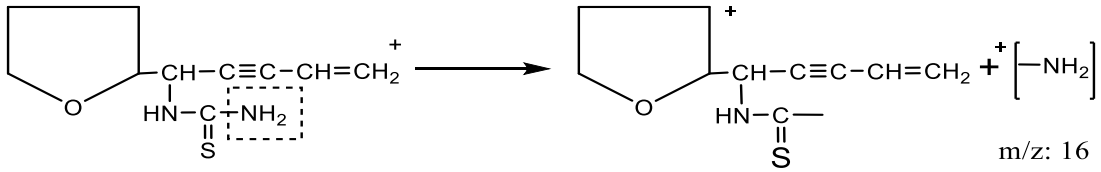
For the amino group –NH_2 in thiourea, two absorptions are observed in the region 3400–3200 cm^{-1}; for the thiocarbonyl group –C=S, in the region 1400–1100 cm^{-1}; the deformation vibration of the –C≡C– group is recorded at 2120 cm^{-1}; for the secondary bond RHC=CH_2 — 1645 cm^{-1}; for the carbonyl group C=O — 1668.43 cm^{-1}; for C=S — 1014.56 cm^{-1}; for the C–H bond — 756.10 cm^{-1}; for the unsaturated acetylene group — 1869.02 cm^{-1}; for the furan ring — 1558–1474 cm^{-1}; and for the aromatic C=C bond — 1281–1157 cm^{-1}.

Additionally, the structure of the new compound can be inferred from the fragmentation sequence in the chromatograph–mass spectrum. After introducing 1-(1-(tetrahydrofuran-2-yl) pent-4-en-2-yn-1-yl) thiourea into the chromatograph–mass spectrometer, under the selected conditions, the molecular ion of 1-(1-(tetrahydrofuran-2-yl) pent-4-en-2-yn-1-yl) thiourea with m/z 210 was detected in the retention time range of 10.639 to 10.708 minutes.





1-(1-(tetrahydrofuran-2-yl)pent-4-en-2-yn-1-yl)thiourea



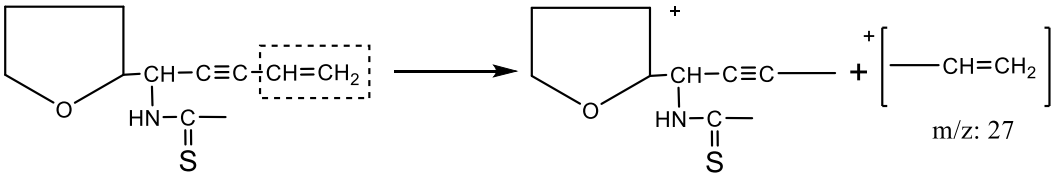
m/z: 210

m/z: 194

m/z: 16

Chemical Formula: $C_{10}H_{14}N_2OS$

Additionally, the spectrum showed the formation of fragment ions with m/z 209, m/z 194, m/z 167, m/z 143, m/z 84, and m/z 59. At 10.639 minutes, the loss of a hydroxyl (–OH) radical from the 1-(1-(tetrahydrofuran-2-yl) pent-4-en-2-yn-1-yl) thiourea ion resulted in the formation of the m/z 194 ion. This peak corresponds to the N-(1-(tetrahydrofuran-2-yl) pent-4-en-2-yn-1-yl) ethanethioamide ion and is consistent with the associated bond energies.

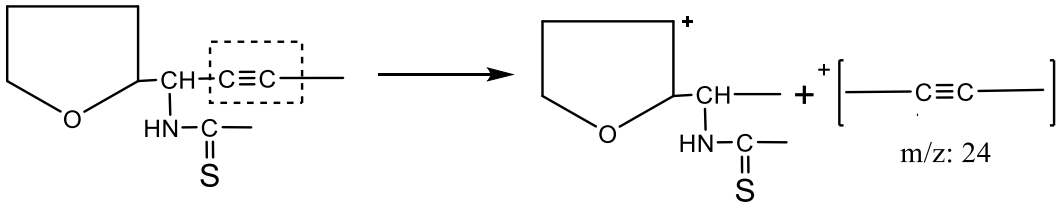


m/z: 194

m/z: 167

N-(1-(tetrahydrofuran-2-yl)pent-4-en-2-yn-1-yl)ethanethioamide

From the tertiary N-(1-(tetrahydrofuran-2-yl) pent-4-en-2-yn-1-yl) ethanethioamide ion, the loss of a methylene radical results in the formation of the m/z 167 ion. This peak corresponds to N-(1-(tetrahydrofuran-2-yl) -2-yn-1-yl) ethanethioamide.

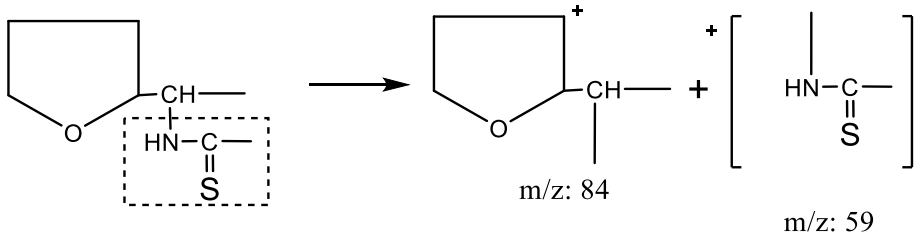


m/z: 167

m/z: 143

N-(1-(tetrahydrofuran-2-yl)but-2-yn-1-yl)ethanethioamide

In turn, from the N-(1-(tetrahydrofuran-2-yl) but-2-yn-1-yl) ethanethioamide ion, at 10.708 minutes, the loss of radicals resulted in the formation of the m/z 59 ion.



m/z: 143

N-(1-(tetrahydrofuran-2-yl)ethyl)ethanethioamide

At the end of the analysis, the kinetics of the resulting N-(1-(tetrahydrofuran-2-yl) ethyl) ethanethioamide ions occur in accordance with the complexity of ring opening. In the initial stage, the cleavage of ions from the side chain, followed by the fragmentation of the ring, confirms the correctness and precise identification of the compound's structure, consistent with the observed fragmentation patterns.

3. CONCLUSION

Using polysilicic acid and the sol–gel method, organic–inorganic hybrid composites were obtained with the involvement of the vinylfurfuryl thiourea sodium tripolyphosphate copolymer. The structure of the composites is formed by a three-dimensional silica dioxide matrix with tightly integrated organic copolymers, which provides them with high thermal and chemical stability. New copolymers based on the system 1-(1-(tetrahydrofuran-2-yl) pent-4-en-2-yn-1-yl) thiourea were synthesized via radical copolymerization in DMSO solution at 85 °C in the presence of an initiator for 3 hours, achieving a yield of 74 %. The hybrid composites based on 1-

(1-(tetrahydrofuran-2-yl) pent-4-en-2-yn-1-yl) thiourea, sodium tripolyphosphate, and polysilicic acid exhibit high sorption activity toward calcium, magnesium, copper, nickel, and iron ions in both acidic and alkaline media. Chromatography-mass spectrometry identified the molecular ion of 1-(1-(tetrahydrofuran-2-yl) pent-4-en-2-yn-1-yl) thiomochelavin, confirmed its complete structure through the fragmentation sequence, and demonstrated that the resulting fragment ions correspond to the unambiguous identification of the compound.

REFERENCE

1. Li, B., Chen, M., Pan, Y., & Yang, L. (2025). Insights into the pyrolysis/gasification mechanism of cation ion exchange resins based on ReaxFF simulation and DFT computation. Thermochimica Acta, 180091.
2. Chavez-Sifontes, M. H., Domine, M. E., & Valencia, S. (2015). Synthesis of furan derivatives via cascade-type reactions catalyzed by solid acids. Catalysis Today, 257, 305-317.
3. Mori, M., Tanaka, K., Satori, T., Ikedo, M., Hu, W., & Itabashi, H. (2006). Influence of acidic eluent for retention behaviors of common anions and cations by ion-exclusion/cation-exchange chromatography on a weakly acidic cation-exchange resin in the H+-form. Journal of Chromatography A, 1118(1), 51-55.
4. Khollieva M., Zhumaeva M., Ostonov F. Synthesis of ionites based on N-vinylmorpholine and craton aldehyde //AIP Conference Proceedings. – AIP Publishing LLC, 2025. – Т. 3304. – №. 1. – С. 040066.
5. Ostonov F., Akhmedov V., Olimov B. Preparation of hybrid composites by sol-gel method and analysis of its properties //Scientific Collection «InterConf». – 2022. – №. 123. – С. 256-259.
6. Zuhriddin, R., & Niginabonu, J. (2022). Production of polyethylene terephthalate. Universum: технические науки, (5-11 (98)), 58-62.
7. Ulugbek Bekov, Firuz Rakhimov, Voxid Axmedov, Akmalxon Rakhimov; Differential thermal analysis of organic silicon compound based on carbolic acid. AIP Conf. Proc. 21 July 2025; 3304 (1): 040067. https://doi.org/10.1063/5.0270303
8. Zuhriddin, R., Niginabonu, J., Aminjon, V., & Temurbek, D. (2022). Mechanisms of eterification of tereftalic acid with etylenglycol. Universum: технические науки, (5-11 (98)), 63-67.
9. Nigina J., Mizrob Z. Production of vinyl ethers of furfuryl alcohol //Universum: химия и биология. – 2023. – №. 9-2 (111). – С. 57-62.
10. Kurbanov F. P. et al. Investigation of the degree of inhibitor protection relative to conditions at different depths //AIP Conference Proceedings. – AIP Publishing LLC, 2025. – Т. 3304. – №. 1. – С. 040081.
11. Niyozov E. et al. Investigation of physicochemical properties of guanidine-based corrosion inhibitor //E3S Web of Conferences. – EDP Sciences, 2024. – Т. 587. – С. 03004.
12. Tanaka, K., Ohta, K., Haddad, P. R., Fritz, J. S., Miyanaga, A., Hu, W., ... & Sarzanini, C. (2001). High-performance ion-exclusion/cation-exchange chromatography of anions and cations in acid rain waters on a weakly acidic cation-exchange resin. Journal of Chromatography A, 920(1-2), 239-245.
13. Venegas-García, D. J., Mir, M., Steiger, B. G., & Wilson, L. D. (2024). Furfuryl-pyridinium-functionalization of flaxseed gum for effective methylene blue removal from aqueous solution. Canadian Journal of Chemistry.