ABSTRACT AND REFERENCES

ECOLOGY. TECHNOLOGY OF ORGANIC AND INORGANIC SUBSTANCES

**DOI**: 10.15587/1729-4061.2017.96572

## INVESTIGATION OF COMPOSITION AND STRUCTURE OF TRIPOLIPHOSPHATE COATING ON LOW CARBON STEEL (p. 4-10)

**Olena Vlasova**
SHEI «National Metallurgical Academy of Ukraine», Dnipro, Ukraine
**ORCID**: http://orcid.org/0000-0002-6814-409X

**Vadym Kovalenko**
SHEI «Ukrainian State University of Chemical Technology», Dnipro, Ukraine
FSBEI HE «Vyatka State University», Kirov, Russian Federation
**ORCID**: http://orcid.org/0000-0002-8012-6732

**Valerii Kotok**
SHEI «Ukrainian State University of Chemical Technology», Dnipro, Ukraine
FSBEI HE «Vyatka State University», Kirov, Russian Federation
**ORCID**: http://orcid.org/0000-0001-8879-7189

**Sergey Vlasov**
SHEI «National Mining University», Dnipro, Ukraine
FSBEI HE «Vyatka State University», Kirov, Russian Federation
**ORCID**: http://orcid.org/0000-0002-5537-6342

**Irina Sknar**
SHEI «Ukrainian State University of Chemical Technology», Dnipro, Ukraine
**ORCID**: http://orcid.org/0000-0001-8433-1285

**Anna Cheremysinova**
SHEI «Ukrainian State University of Chemical Technology», Dnipro, Ukraine
**ORCID**: http://orcid.org/0000-0002-7877-1257

The hypothesis on the matrix (composite) structure of the iron (III) tripolyphosphate precipitate and polyphosphate coatings on the steel substrate has been justified experimentally. According to the hypothesis, that iron (III) tripolyphosphate acts as a matrix forming agent while water-soluble sodium tripolyphosphate corrosion inhibitor is a filler.

Be means of the chemical synthesis method, it has been demonstrated that the chemical basis of the coating formed on the steel surface in the STPP solution is iron (III) tripolyphosphate.

It has been established that the composite structure of tripolyphosphate coatings and precipitates is determined by the nature of iron (III) tripolyphosphate.

The conducted investigation on the composition of the iron (III) tripolyphosphate precipitate and tripolyphosphate coating on steel, using the gravimetric method with washing have proved the presence of STPP. The results of X-ray spectral analysis have revealed that STPP in the structure of composite coating is situated not only as a filler inside the matrix but also as an additional layer on its surface.

The chemical protection mechanism of the tripolyphosphate coating on steel in atmospheric conditions has been justified.

The acquired knowledge would expand the theoretical and practical concept of the structure and properties of tripolyphosphate coatings on the steel substrate and their protection mechanism in conditions of atmospheric corrosion. The application of new knowledge in researches aimed at the development of ecologically safe methods of tripolyphosphate coating deposition with estimated complex of properties, would increase their efficiency.

**Keywords**: sodium tripolyphosphate, iron (III) tripolyphosphate, precipitate, coating, protective properties, matrix structure, chemical synthesis.

**References**

1. Grigoryan, N. S., Akimova, E. F., Vagramyan, T. A. (2008). Fosfatirovanie. Moscow: Globus, 144.
2. Akol'zin, A. P. (1989). Protivokorrozionnaya zashchita stali plenkoobrazova-telyami. Moscow: Metallurgiya, 192.
3. Lipkin, Ya. N., Shtan'ko, V. M. (1974). Himicheskaya i ehlektrohimicheskaya obrabotka stal'nyh trub. Moscow: Metallurgiya, 216.
4. Cheremysinova, A. O., Panasenko, S. P. (2010). Pat. No. 94340 UA. Mastylo dlya prokatky stal'nykh bezshovnykh trub ta sposib yoho oderzhannya. MPK S 10 M 103/00, S 10 M 177/00. No. a201001874; declareted: 22.02.2010; published: 26.04.2011, Bul. No. 8, 3.
5. Abdalla, K., Rahmat, A., Azizan, A. (2012). The Effect of pH on Zinc Phosphate Coating Morphology and its Corrosion Resistance on Mild Steel. Advanced Materials Research, 626, 569–574. doi: 10.4028/www.scientific.net/amr.626.569
6. Tumbaleva, Y., Ivanova, D., Fachikov, L. (2011). Effect of the $P_2O_5$:$NO_3$ – retio on the zink phosphate coating formation. Journal of the University of Chemical Technology and Metallurgy, 46 (4), 357–362.
7. Kuznecov, Yu. I. (2001). Ingibitory korrozii v konversionnyh pokrytiyah III. Zashchita metallov ot korrozii, 37 (2), 119–125.
8. Piani, L., Papo, A. (2013). Sodium Tripolyphosphate and Polyphosphate as Dispersing Agents for Alumina Suspensions: Rheological Characterization. Journal of Engineering, 2013, 1–4. doi: 10.1155/2013/930832
9. Ait-Salah, A., Ramana, C. V., Gendron, F., Morhange, J. F., Mauger, A., Zaghib, K., Julien, C. (2007). Synthesis, Structure and Electrochemical Properties of LiFe2P3O10 Synthesized by Wet Chemistry. ECS Transactions, 3 (36), 95–100. doi: 10.1149/1.2795110
10. Rozenfel'd, I. L. (1977). Ingibitory korrozii. Mosocw: Himiya, 352.
11. Ltifi, M., Guefrech, A., Mounanga, P. (2011). Effects of sodium tripolyphosphate addition on early-age physico-chemical properties of cement pastes. Procedia Engineering, 10, 1457–1462. doi: 10.1016/j.proeng.2011.04.242
12. Deya, M., Di Sarli, A. R., del Amo, B., Romagnoli, R. (2008). Performance of Anticorrosive Coatings Containing Tripolyphosphates in Aggressive Environments. Industrial & Engineering Chemistry Research, 47 (18), 7038–7047. doi: 10.1021/ie071544d
13. Deya, M., Vetere, V. F., Romagnoli, R., del Amo, B. (2001). Aluminium tripolyphosphate pigments for anticorrosive paints. Pigment & Resin Technology, 30 (1), 13–24. doi: 10.1108/03699420110364129

14. Vetere, V. F., Deya, M. C., Romagnoli, R., Amo, B. (2001). Calcium tripolyphosphate: An anticorrosive pigment for paint. Journal of Coatings Technology, 73 (6), 57–63. doi: 10.1007/bf02698398
15. Yanga, Y. F., Scantleburya, J. D., Koroleva, E., Ogawab, O., Tanabeb, H. (2010). A Novel Anti-corrosion Calcium Magnesium Polyphosphate Pigment and Its Performance in Aqueous Solutions on Mild Steel. ECS Transactions, 24 (1), 77–85. doi: 10.1149/1.3453608
16. Yanga, Y. F., Scantlebury, J. D., Koroleva, E., Ogawa, O., Tanabe, H. (2010). A Novel Anti-corrosion Calcium Magnesium Polyphosphate Pigment and its Performance in Aqueous Solutions on Mild Steel When Coupled to Metallic Zinc. ECS Transactions, 24 (1), 163–168. doi: 10.1149/1.3453615
17. Burlov, V. V., Al'cybeeva, A. I., Kuzikova, T. M. (2011). Lokal'naya korroziya oborudovaniya sovremennogo nefte-pererabatyvayushchego zavoda. Izvestiya Sankt-Peterburgskogo gosudarstvennogo tekhnolo-gicheskogo universiteta (tekhnicheskogo universiteta), 11 (37), 92–96.
18. Kheireddine, A., Fahim, I. (2013). Sodium tripolyphosphate (STPP) as a novel corrosion inhibitor for mild steel in 1M HCL. Journal of optoelectronics and advanced materials, 15 (5-6), 451–456.
19. Yohai, L., Schreiner, W., Valcarce, M. B., Vazquez, M. (2016). Inhibiting Steel Corrosion in Simulated Concrete with Low Phosphate to Chloride Ratios. Journal of The Electrochemical Society, 163 (13), C729–C737. doi: 10.1149/2.0511613jes
20. Lee, S.-J., Toan, D. L. H., Chen, Y.-H., Peng, H.-C. (2016). Performance Improvement of Phosphate Coating on Carbon Steel by Cathodic Electrochemical Method. Int. J. Electrochem. Sci., 11, 2306–2316.
21. Vlasova, E., Kovalenko, V., Kotok, V., Vlasov, S. (2016). Research of the mechanism of formathion and properties of tripolyphosphate coatingon the steel basis. Eastern-European Journal of Enterprise Technologies, 5 (5 (83)), 33–39. doi: 10.15587/1729-4061.2016.79559
22. Vlasova, E. V., Karasik, T. L. (2010). Issledovanie pokrytij, poluchennyh iz vodnyh rastvorov fosfatov. Metallurgicheskaya i gornorudnaya promyshlennost', 5, 89–91.
23. Vlasova, E. V., Karasik, T. L., Levko, E. N., Kovalenko, V. L., Lizogub, A. A. (2011). Rolled metal products functional coatings based on alkali metals phosphates. Eastern-European Journal of Enterprise Technologies, 5 (6 (53)), 30–33. Available at: http://journals.uran.ua/eejet/article/view/1244/1146
24. Sutchenko, A. S., Vlasova, E. V., Yaroshenko, N. V. (2014). Issledovanie struktury i svojstv sovremennyh mezhoperacionnyh pokrytij. Innovacionnyj potencial miro-voj nauki XXI stoletiya, 61–62.
25. Kovalenko, V. L., Kotok, V. A., Sykchin, A. A., Mudryi, I. A., Ananchenko, B. A., Burkov, A. A. et. al. (2016). Nickel hydroxide obtained by high-temperature two-step synthesis as an effective material for supercapacitor applications. Journal of Solid State Electrochemistry, 21 (3), 683–691. doi: 10.1007/s10008-016-3405-2
26. Kovalenko, V., Kotok, V., Bolotin, O. (2016). Definition of factors influencing on $Ni(OH)_2$ electrochemical characteristics for supercapacitors. Eastern-European Journal of Enterprise Technologies, 5 (6 (83)), 17–22. doi: 10.15587/1729-4061.2016.79406
27. Burmistr, M. V., Boiko, V. S., Lipko, E. O., Gerasimenko, K. O., Gomza, Y. P., Vesnin, R. L. et. al. (2014). Antifriction and Construction Materials Based on Modified Phenol-Formaldehyde Resins Reinforced with Mineral and Synthetic Fibrous Fillers. Mechanics of Composite Materials, 50 (2), 213–222. doi: 10.1007/s11029-014-9408-0


**DOI**: 10.15587/1729-4061.2017.95699

## OBTAINING OF Ni–Al LAYERED DOUBLE HYDROXIDE BY SLIT DIAPHRAGM ELECTROLYZER (p. 11-17)

**Vadym Kovalenko**
Ukrainian State University of Chemical Technology, Dnipro, Ukraine
Federal State Educational Institution of Higher Education "Vyatka State University", Kirov, Russian Federation
**ORCID**: http://orcid.org/0000-0002-8012-6732

**Valerii Kotok**
Ukrainian State University of Chemical Technology, Dnipro, Ukraine
Federal State Educational Institution of Higher Education "Vyatka State University", Kirov, Russian Federation
**ORCID**: http://orcid.org/0000-0001-8879-7189

Ni–Al layered double hydroxides are promising cathode materials for Ni–Cd, Ni–Fe and Ni–MeH accumulators with improved characteristics. However, they are prepared using batch methods which cannot guarantee the stability of their characteristics. The main aim of the present work was the development of a continuous method of electrochemical synthesis of highly active Ni–Al layered double hydroxide in a slit diaphragm electrolyzer (SDE). A study on the influence of current density and anolyte composition (NaOH or NaOH+$Na_2CO_3$ at different ratios) on the electrochemical properties of NI-Al hydroxide has been conducted. The LDH structure has been proven by means of X-ray diffraction analysis. It has been demonstrated that synthesis of Ni-Al LDH in SDE must be conducted at high current densities at which formation rate of hydroxyl anions would exceed the supply rate of cations. This would prevent the presence of aluminum cations in the solution that causes poisoning upon adsorption on the hydroxide surface. It has been demonstrated that introduction of sodium carbonate into the anolyte is not feasible, because of the possibility of complete hydrolysis of $Al^{3+}$ in the presence of $CO_3^{2-}$ with the formation of the $Al(OH)_3$ phase. This phase is capable of dissolving in alkaline electrolyte and poisoning the nickel hydroxide electrode. Optimal parameters for the synthesis of Ni–Al LDH in SDE have been established: current density – 18 A/dm$^2$, anolyte – NaOH solution. Ni–Al LDH, synthesized in SDE at these conditions, demonstrated the specific capacity of 237 mA·h/g. This exceeds capacities of chemically synthesized Ni-Al LDH (211 mA·h/g) and industrial sample (185 mA·h/g).

**Keywords**: Ni–Al layered double hydroxide, electrochemical synthesis, slit diaphragm electrolyzer.

**References**


1. Posada, J. O. G., Rennie, A. J. R., Villar, S. P., Martins, V. L., Marinaccio, J., Barnes, A. et. al. (2017). Aqueous batteries as grid scale energy storage solutions. Renewable and Sustainable Energy Reviews, 68, 1174–1182. doi: 10.1016/j.rser.2016.02.024
2. Hall, D. S., Lockwood, D. J., Poirier, S., Bock, C., MacDougall, B. R. (2012). Raman and Infrared Spectroscopy of α and β Phases of Thin Nickel Hydroxide Films Electrochemically Formed on Nickel. The Journal of Physical Chemistry A, 116 (25), 6771–6784. doi: 10.1021/jp303546r
3. Vidotti, M., Torresi, R., de Torresi, S. I. C. (2010). Eletrodos modificados por hidroxido de niquel: um estudo de revisao sobre suas propriedades estruturais e eletroquimicas visando suas aplicacoes em eletrocatalise, eletrocromismo e baterias secundarias. Quimica Nova, 33 (10), 2176–2186. doi: 10.1590/s0100-40422010001000030
4. Kovalenko, V. L., Kotok, V. A., Sykchin, A. A., Mudryi, I. A., Ananchenko, B. A., Burkov, A. A. et. al. (2016). Nickel hydroxide obtained

by high-temperature two-step synthesis as an effective material for supercapacitor applications. Journal of Solid State Electrochemistry, 21 (3), 683–691. doi: 10.1007/s10008-016-3405-2
5. Kovalenko, V., Kotok, V., Bolotin, O. (2016). Definition of factors influencing on Ni(OH)2 electrochemical characteristics for supercapacitors. Eastern-European Journal of Enterprise Technologies, 5 (6 (83)), 17–22. doi: 10.15587/1729-4061.2016.79406
6. Hu, M., Yang, Z., Lei, L., Sun, Y. (2011). Structural transformation and its effects on the electrochemical performances of a layered double hydroxide. Journal of Power Sources, 196 (3), 1569–1577. doi: 10.1016/j.jpowsour.2010.08.041
7. Bao, J., Zhu, Y. J., Xu, Q. S., Zhuang, Y. H., Zhao, R. D., Zeng, Y. Y., Zhong, H. L. (2012). Structure and Electrochemical Performance of Cu and Al Codoped Nanometer α-Nickel Hydroxide. Advanced Materials Research, 479-481, 230–233. doi: 10.4028/www.scientific.net/amr.479-481.230
8. Solovov, V., Kovalenko, V., Nikolenko, N., Kotok, V., Vlasova, E. (2017). Influence of temperature on the characteristics of Ni(II), Ti(IV) layered double hydroxides synthesised by different methods. Eastern-European Journal of Enterprise Technologies, 1 (6 (85)), 16–22. doi: 10.15587/1729-4061.2017.90873
9. Zhou, F., Zhao, X., van Bommel, A., Rowe, A. W., Dahn, J. R. (2010). Coprecipitation Synthesis of NixMn1-x(OH)2Mixed Hydroxides. Chemistry of Materials, 22 (3), 1015–1021. doi: 10.1021/cm9018309
10. Rocha, M. A., Winnischofer, H., Araki, K., Anaissi, F. J., Toma, H. E. (2011). A New Insight on the Preparation of Stabilized Alpha-Nickel Hydroxide Nanoparticles. Journal of Nanoscience and Nanotechnology, 11 (5), 3985–3996. doi: 10.1166/jnn.2011.3872
11. Qi, J., Xu, P., Lv, Z., Liu, X., Wen, A. (2008). Effect of crystallinity on the electrochemical performance of nanometer Al-stabilized α-nickel hydroxide. Journal of Alloys and Compounds, 462 (1-2), 164–169. doi: 10.1016/j.jallcom.2007.07.102
12. Li, Y. W., Yao, J. H., Liu, C. J., Zhao, W. M., Deng, W. X., Zhong, S. K. (2010). Effect of interlayer anions on the electrochemical performance of Al-substituted α-type nickel hydroxide electrodes. International Journal of Hydrogen Energy, 35 (6), 2539–2545. doi: 10.1016/j.ijhydene.2010.01.015
13. Hu, B., Chen, S.-F., Liu, S.-J., Wu, Q.-S., Yao, W.-T., Yu, S.-H. (2008). Controllable Synthesis of Zinc-Substituted α- and β-Nickel Hydroxide Nanostructures and Their Collective Intrinsic Properties. Chemistry – A European Journal, 14 (29), 8928–8938. doi: 10.1002/chem.200800458
14. Gong, L., Liu, X., Su, L. (2011). Facile Solvothermal Synthesis $Ni(OH)_2$ Nanostructure for Electrochemical Capacitors. Journal of Inorganic and Organometallic Polymers and Materials, 21 (4), 866–870. doi: 10.1007/s10904-011-9519-1
15. Yang, L.-X., Zhu, Y.-J., Tong, H., Liang, Z.-H., Li, L., Zhang, L. (2007). Hydrothermal synthesis of nickel hydroxide nanostructures in mixed solvents of water and alcohol. Journal of Solid State Chemistry, 180 (7), 2095–2101. doi: /10.1016/j.jssc.2007.05.009
16. Xu, L., Ding, Y.-S., Chen, C.-H., Zhao, L., Rimkus, C., Joesten, R., Suib, S. L. (2008). 3D Flowerlike α-Nickel Hydroxide with Enhanced Electrochemical Activity Synthesized by Microwave-Assisted Hydrothermal Method. Chemistry of Materials, 20 (1), 308–316. doi: 10.1021/cm702207w
17. Fomanyuk, S. S., Krasnov, Y. S., Kolbasov, G. Y. (2013). Kinetics of electrochromic process in thin films of cathodically deposited nickel hydroxide. Journal of Solid State Electrochemistry, 17 (10), 2643–2649. doi: 10.1007/s10008-013-2169-1
18. Kovalenko, V. L., Kotok, V. A., Malishev, V. V. (2008). Electrochemical obtaining of $Ni(OH)_2$ from sulphate solution by flowing slit diafragm electrolyzer. RSE-SEE, 1st regional symposium on electrochemistry of South-East Europe. Rovinj, Croatia, 201–203.
19. Kovalenko, V. L., Kotok, V. A. (2015). The synthesis of nickel hydroxide by electrolysis from nickel nitrate solution in the slit diaphragm electrolyzer. Electrochemical properties. Collection of research papers of National mining university, 49, 181–186.
20. Kotok, V. A., Koshel, N. D., Kovalenko, V. L., Grechanuk, A. A. (2008). The stability of aluminium-substituted alpha-nickel hydroxide. First Regional Symposium on Electrochemistry of South-East Europe "RSE-SEE". Croatia Rovinj, 204–206.
21. Kotok, V., Kovalenko, V. (2017). Optimization of nickel hydroxide electrode of the hybrid supercapacitor. Eastern-European Journal of Enterprise Technologies, 1 (6 (85)), 4–9. doi: 10.15587/1729-4061.2017.90810

**DOI**: 10.15587/1729-4061.2017.96464

## SYSTEM ANALYSIS OF THE SECONDARY CONDENSATION UNIT IN THE CONTEXT OF IMPROVING ENERGY EFFICIENCY OF AMMONIA PRODUCTION (p. 18-26)

**Anatoliy Babichenko**
National Technical University
"Kharkiv Polytechnic Institute", Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0002-8649-9417

**Vladimir Velma**
National University of Pharmacy, Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0002-3799-5393

**Juliya Babichenko**
Ukrainian State University of Railway Transport, Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0002-5345-7595

**Yana Kravchenko**
National Technical University
"Kharkiv Polytechnic Institute", Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0002-6311-8060

**Igor Krasnikov**
National Technical University
"Kharkiv Polytechnic Institute", Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0002-7663-1816

We established the mismatch between real and design coefficients of heat transfer, which is predetermined by the underestimation of condensation thermal resistance. The processes of heat exchange in a condensation column are identified and the equations for determining the coefficients of heat exchange, heat transfer and the concentration of ammonia in the circulation gas at the outlet of the column are derived. By applying the method of mathematical modeling, we defined necessary conditions for temperature distribution to exclude from the circuit of the unit for synthesis a turbo-compressor refrigeration unit with electric drive of capacity up to 4000 kW·h and reduction in the cooling temperature of circulation gas from 0 °C to – 5 °C at maximum thermal load with circulation gas on the complex of secondary condensation.

The hardware-technological design is developed for the stage of secondary condensation based only on the absorption and steam-ejector refrigeration systems that utilize the heat of material flows of low (above 100 °C) and super-low (to 90 °C) potentials. We defined efficiency indicators for the reduction of specific energy consumption by electricity and natural gas, which are 60 kW·h/t $NH_3$ and 1.2 $m^3$/t $NH_3$.

**Keywords**: production of ammonia, secondary condensation, identification, mathematical modeling of the processes of heat exchange, energy efficiency.

**References**

1. Winiwarter, W., Erisman, J. W., Galloway, J. N., Klimont, Z., Sutton, M. A. (2013). Estimating environmentally relevant fixed nitro-

gen demand in the 21st century. Climatic Change, 120 (4), 889–901. doi: 10.1007/s10584-013-0834-0
2. Dawson, C. J., Hilton, J. (2011). Fertiliser availability in a resource-limited world: Production and recycling of nitrogen and phosphorus. Food Policy, 36, S14–S22. doi: 10.1016/j.foodpol.2010.11.012
3. Dybkjoker, I. (2013). 100 Years of Ammonia Synthesis Technology. 58th Annual Safety in Ammonia Plants and Related Facilities Symposium. Frankhfurt. Available at: https://www.aiche.org/sites/default/files/docs/conferences/8096_Ammonia2013_Committee_Flyer_v8_0.pdf
4. Noelker, K., Ruether, J. (2011). Low Energy Consumption Ammonia Production: Baseline Energy Consumption, Options for Energy Optimization. Paper submitted for the Nitrogen + Syngas Conference. Duesseldorf. Available at: https://ru.scribd.com/document/317686530/Low-Energy-Consumption-Ammonia-Production-2011-paper-pdf
5. Babichenko, A. K., Toshynsjkyj, V. I. (2009). Zastosuvannia matematychnogho modeljuvannia dlia diaghnostyky pokaznykiv efektyvnosti procesiv teplo- i masoobminu v absorberakh teplovykorystovujuchykh kholodyljnykh ustanovok aghreghativ syntezu amiaku. Voprosy khimii i khimicheskoy tekhnologii, 6, 107–111.
6. Malhotra, A. (2012). KBR PURIFIER™ Technology and Project Execution Options for Ammonia Plants. 25th AFA International Fertilizer Technology Conference & Exhibition Sustainability Driving the Future. KBR, USA. Available at: http://s3.amazonaws.com/zanran_storage/afa.com.eg/ContentPages/2565221218.pdf
7. Singh, U., Singh, S., Malhotra, A. (2010). Successful Operating Experience of CFCL Ammonia Plant Revamped with KBR KRES™ Technology. Ammonia plant safety (and related facilities). Safety in ammonia plants & related facilities symposium. Montreal, 121–130.
8. Arora, V. K. (2015). Use multistage integrated chilling to increase ammonia production. Hydrocarbon processing, 94 (4), 39–48
9. Babichenko, A. K., Toshinskiy, V. I., Krasnikov, I. L., Podustov, M. A. (2007). Energosberegayushchee tekhnologicheskoe oformlenie bloka vtorichnoy kondensatsii krupnotonnazhnykh agregatov sinteza ammiaka. Integrated Technologies and Energy Conservation, 4, 3–6.
10. Ladanjuk, A. P., Ladanjuk, O. A., Bojko, R. O. et. al. (2015). Suchasni metody avtomatyzacii tekhnologhichnykh ob'iektiv. Kyiv: Integhr. Loghistyk Ukraina, 408.
11. Brandt, S. (2014). Data Analysis: Statistical and Computational Methods for Scientists and Engineers. New York: Springer, 523. doi: 10.1007/978-3-319-03762-2
12. Babichenko, A. K. (2010). Conformities to the law of heat exchange in the process of condensation of ammonia of products from circulation gas in viparnikakh of aggregates of synthesis, 1, 47–51.

**DOI**: 10.15587/1729-4061.2017.95633

**MATHEMATICAL MODELING OF THE DYNAMICS OF HOMOGENEOUS REACTIONS IN THE CASCADE OF PERFECT MIXING REACTORS (p. 27-32)**

**Svitlana Prymyska**
National Technical University of Ukraine
"Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
**ORCID**: http://orcid.org/0000-0002-5832-0686

**Yuri Beznosyk**
National Technical University of Ukraine
"Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
**ORCID**: http://orcid.org/0000-0001-7425-807X

**Wladimir Reschetilowski**
Institute Technical Chemistry,
Dresden University of Technology, Dresden, Germany
**ORCID**: http://orcid.org/0000-0002-2333-798X

Present study tackles theoretical analysis and mathematical modeling of the process of homogeneous first-order reaction in the cascade of perfect mixing reactors of continuous action (PMR-C). The modeling of chemical reactors is based on the thermal and material balances in combination with chemical kinetics. The mathematical model of the dynamics of the process of homogeneous first-order reaction in the PMR-C cascade is represented in the form of equations of change in the molar fraction of substance over time and a change in the inner energy of the ideal flow of substance. In the present work, we calculated, by the mathematical model, the process of acetic anhydride hydrolysis in 5 sequentially connected PMR-C. Calculation by the model is performed by the Runge-Kutta method of third order. We obtained temperature profiles for the dynamics of the process of acetic anhydride hydrolysis for a cascade of PMR-C. The temperature gradient in reactor grows over time; consequently, it takes on a constant value. We analyzed the impact of the volume of reaction mixture on the depth of the course of the process both for the separate perfect mixing reactors and for the cascade of perfect mixing reactors. With an increase in the volume of mixture, the reaction rate increases, while the speed of reaching the necessary degree of conversion decreases. The speed of reaching the maximum degree of conversion for the cascade of reactors compared with one perfect mixing reactor of the same volume is considerably higher. Recommendations regarding the course of the process are formulated. We calculated the value of cost for conducting the process of acetic anhydride hydrolysis depending on the change in temperature. Minimum cost is attained at temperature 341 K and amounts to UAH 1.70 million per year.

**Keywords**: dynamics of the process, cascade of perfect mixing reactors, acetic anhydride, degree of conversion.

**References**

1. Saad, M., Albagul, A., Obiad, D. (2013). Modeling and Control Design of Continuous Stirred Tank Reactor System. Proceedings of the 15th International Conference on Automatic Control, Modelling & Simulation (ACMOS '13). Brasov, 344–348.
2. Shyamalagowri, M., Rajeswari, R. (2013). Modeling and simulation of non-liner process control reactor – CSTR. International Journal of Advances in Engineering & Technology, 6 (4), 1813–1818.
3. Egedy, A., Varga, T., Chovan, T. (2011). Application of models with different complexity for a stirred tank reaktor. Hungarian Journal of Industry and Chemistry, 39 (3), 335–339.
4. Caccavale, F., Iamarino, M., Pierri, F., Tufano, V. (2011). Control and Monitoring of Chemical Batch Reactors. The Chemical Batch Reactor. Advances in Industrial Control. Springer-Verlag London Limited, 9–38. doi: 10.1007/978-0-85729-195-0_2
5. Nogueira, A. G., Silva, D. C. M., Baptista, C. M. S. G. (2016). Modeling Real Flow in a Continuous Stirred Liquid–Liquid System. Industrial & Engineering Chemistry Research, 55 (1), 71–79. doi: 10.1021/acs.iecr.5b03236
6. Prokopova, Z., Prokop, R. (2009). Modelling and simulation of chemical industrial reactors. 23rd European conference on modelling and simulation. Madrid, 1–6. doi: 10.7148/2009-0378-0383
7. Suja Malar, R. M., Thyagarajan, T. (2009). Modelling of continuous stirred tank reactor using artificial intelligence techniques. International Journal of Simulation Modelling, 8 (3), 145–155. doi: 10.2507/ijsimm08(3)2.128
8. Couenne, F., Jallut, C., Maschke, B., Breedveld, P. C., Tayakout, M. (2006). Bond graph modelling for chemical reactors. Mathematical and Computer Modelling of Dynamical Systems, 12 (2-3), 159–174. doi: 10.1080/13873950500068823
9. Rahmat, M. F., Yazdani, A. M., Movahed, M. A., Mahmoudzadeh, S. (2011). Temperature control of a continuous stirred tank reactor by

means of two intelligent strategies. International Journal on Smart Sensing and Intelligent Systems, 4 (2), 244–267.
10. Kanse Nitin, G., Dhanke, P., Thombare, A. (2012). Modeling and Simulation Study of the CSTR for Complex Reaction by Using Polymath. Research Journal of Chemical Sciences, 2 (4), 79–85.
11. Prymyska, S., Beznosyk, Y., Reschetilowski, W. (2015). Simulation the gas simulataneous adsorption over natural and modified zeolite. Eastern-European Journal of Enterprise Technologies, 2 (6 (74)), 34–37. doi: 10.15587/1729-4061.2015.39786
12. Prymyska, S., Beznosyk, Yu., Statyukha, G., Reschetilowski, W. (2009). Research and modeling of adsorption/desorption of nitrogen oxides in zeolites. Naukkovi Visti NTUU "KPI", 5 (61), 109–114.
13. Jayakumar, N. S., Thomas, M., Sahu, J. N. (2014). Experimental and modeling of a non-isothermal CSTR to find out parameter regions and conditions causing input multiplicity for acid catalyzed hydrolysis of acetic anhydride. Chemometrics and Intelligent Laboratory Systems, 135, 213–222. doi: 10.1016/j.chemolab.2014.04.017
14. Kovac, A. (2007). Checking the Kinetics of Acetic Acid Production by Measuring the Conductivity. J. Ind. Eng. Chem., 13 (4), 631–636.
15. Sansar, B. (2013). Optimization of a Chemical Reaction Train. Undergraduate Journal of Mathematical Modeling: One + Two, 2 (2). doi: 10.5038/2326-3652.2.2.9

**DOI**: 10.15587/1729-4061.2017.95626

## THERMAL ANALYSIS AND IR-SPECTROSCOPIC RESEARCH INTO INTERACTION BETWEEN ORGANOSILICON COMPOUNDS AND NONMETALLIC MATERIALS (p. 33-38)

**Nina Merezhko**
Kyiv National University of Trade and Economics, Kyiv, Ukraine
**ORCID**: http://orcid.org/0000-0003-3077-9636

**Oksana Zolotareva**
Kyiv National University of Trade and Economics, Kyiv, Ukraine
**ORCID**: http://orcid.org/0000-0003-2534-3125

**Olga Shulga**
Kyiv National University of Trade and Economics, Kyiv, Ukraine
**ORCID**: http://orcid.org/0000-0003-0312-890X

It is established that the treatment of carbonate and silicate nonmetallic materials with organosilicon compounds is accompanied by the occurrence of endothermic and exothermic effects.

Exothermic effects are associated with the cleavage of radicals in the organosilicon compounds. It was found that the tuff impregnated with ethyl silicate hydrolyzate is characterized by a wider range of removal of radicals – $C_2H_5$. This may be due to their more intense interaction as compared to other non-metallic materials.

Occurrence of endothermic effects is caused by release of water, which formed as a result of interaction between nonmetallic materials and organosilicon compounds.

The strength of bond between organosilicon compounds and non-metallic materials decreases in a series of sodium phenyl siliconate>potassium methyl siliconate>sodium ethyl siliconate.

An interaction between siliconates of alkali metals and silicate non-metallic materials is characterized by a stronger bond than that in the case of carbonate materials. The total loss of mass of impregnated silicates is 5.4–10 % versus 26.1–30.3 % in carbonates.

The data on IR spectroscopy of the impregnated nonmetallic materials also testify to the physical-chemical interaction between carbonates and silicates and organosilicon compounds. The fixation and interaction of siliconates in the composition of carbonates is evidenced by the occurrence on IR spectra of new bands at 2900–3000 $cm^{-1}$ and an increase in the intensity of bands responsible for oscillations in the bonds between silicon and oxygen. The evidence of this is also an increase in adsorbed water and a decrease in the intensity of absorption bands characteristic of anion There is also an expansion in the range of bands responsible for the valence and deformational oscillations in the bonds between silicon and oxygen. There appear the bands that are caused by the deformational oscillations in the bond between C–H and adsorbed water.

The indicated peculiarities allow us to conclude that in the structure of silicates and carbonates there occurs both a physical fixation and a chemical interaction between siliconates of potassium and sodium.

**Keywords**: non-metallic materials, carbonates, silicates, organosilicon compounds, IR-spectroscopy, DTA, DTG, TG.

**References**

1. Schaffer, R. J. (2016). The Weathering of Natural Building Stones. London: Routledge, 206. doi: 10.4324/9781315793771
2. Avila, L. R., de Faria, E. H., Ciuffi, K. J., Nassar, E. J., Calefi, P. S., Vicente, M. A., Trujillano, R. (2010). New synthesis strategies for effective functionalization of kaolinite and saponite with silylating agents. Journal of Colloid and Interface Science, 341 (1), 186–193. doi: 10.1016/j.jcis.2009.08.041
3. Foldvari, M. (2011). Handbook of thermogravimetric system of minerals and its use in geological practice. Budapest: Geological Institute of Hungary, 175.
4. Makarova, I. A., Lohova, N. A. (2011). Fiziko-himicheskie metodyi issledovaniya stroitelnyih materialov. Bratsk: BrGU, 139.
5. Roos, M., Konig, F., Stadtmuller, S., Weyershausen, B. (2008). Evolution of Silicone Based Water Repellents for Modern Building Protection. 5th International Conference on Water Repellent Treatment of Building Materials Aedificatio Publishers, 3–16.
6. El-Esweda, B., Yousefb, R. I. (2012). The Effect of Chemical and Thermal Treatments on the Buffering Capacity of Phillipsite Tuff. Jordan Journal of Earth and Environmental Sciences, 4 (2), 7–14.
7. Nakamoto, K. (2008). Infrared and Raman Spectra of Inorganic and Coordination Compounds: Part A: Theory and Applications in Inorganic Chemistry. Canada: Wiley, 432. doi: 10.1002/9780470405840
8. Ptacek, P., Soukal, F., Opravil, T., Havlica, J., Brandstetr, J. (2011). The kinetic analysis of the thermal decomposition of kaolinite by DTG technique. Powder Technology, 208 (1), 20–25. doi: 10.1016/j.powtec.2010.11.035
9. Wu, K., Zhu, K., Wu, H., Han, J., Wang, J.-C., Huang, Z.-Y., Liang, P. (2014). Influence of limestone fillers on combustion characteristics of asphalt mortar for pavements. Chinese Physics B, 23 (7), 074703. doi: 10.1088/1674-1056/23/7/074703
10. Zhang, W., Qian, H., Sun, Q., Chen, Y. (2015). Experimental study of the effect of high temperature on primary wave velocity and microstructure of limestone. Environmental Earth Sciences, 74 (7), 5739–5748. doi: 10.1007/s12665-015-4591-4
11. Fleysher, H. Yu., Tokarchuk, V. V., Sviders'kyy, V. A. (2016). The effect of nitrogen-containing organic admixtures on the chemical processes of cement hardening. Eastern-European Journal of Enterprise Technologies, 1 (6 (79)), 46–54. doi: 10.15587/1729-4061.2016.59505
12. Kryvenko, P. V., Kovalchuk, O. Iu., Hrabovchak, V. V. (2013). Keruvannia protsesamy strukturoutvorennia luzhnykh zolovmisnykh

tsementiv dlia pokrashchennia vlastyvostei shtuchnoho kamenia. Budivelni materialy, vyroby ta sanitarna tekhnika, 49, 21–27.
13. Villain, G., Thiery, M., Platret, G. (2007). Measurement methods of carbonation profiles in concrete: Thermogravimetry, chemical analysis and gammadensimetry. Cement and Concrete Research, 37 (8), 1182–1192. doi: 10.1016/j.cemconres.2007.04.015
14. Merezhko, N., Zolotarova, O. (2016). Fizyko-tekhnichni vlastyvosti prosochenykh kremniiorhanichnymy spolukamy porystykh nerudnykh materialiv. Tovary i rynky, 2, 73–82.

**DOI**: 10.15587/1729-4061.2017.96114

## FORMATION OF LEATHER BIOSTABILITY WITH THE USE OF CATIONIC POLYELECTROLYTES (p. 39-47)

**Oksana Kozar**
Mukachevo State University, Mukachevo, Ukraine
**ORCID**: http://orcid.org/0000-0001-6649-1699

**Myroslav Sprynskyy**
Nicolaus Copernicus University, Torun, Poland
**ORCID**: http://orcid.org/0000-0002-4334-3594

**Yulia Hrechanyk**
Kyiv National University of Technology and Design, Kyiv, Ukraine
**ORCID**: http://orcid.org/0000-0003-0342-301X

**Olena Ohmat**
Kyiv National University of Technologies and Design, Kyiv, Ukraine
**ORCID**: http://orcid.org/0000-0003-0927-8706

**Katarzyna Lawinska**
Institute of Leather Industry Lodz, Lodz, Poland
**ORCID**: http://orcid.org/0000-0001-5392-9233

**Ruslan Rosul**
Mukachevo State University, Mukachevo, Ukraine
**ORCID**: http://orcid.org/0000-0003-2416-9639

**Valentin Himych**
Mukachevo State University, Mukachevo, Ukraine
**ORCID**: http://orcid.org/0000-0003-4188-356X

The creation of new preparations with a wide range of biocidal action on the pathogenic microorganisms, long-term protective action and, at the same time, with low toxicity for humans and safe for the environment, is a relevant direction in the development of modern technologies in the production of leather materials.

In the present article we report the results of examining the antibacterial properties of leather, modified with a composition of natural minerals (zeolite, montmorillonite) and polyhexamethyleneguanidine hydrochloride (PHMG-HC) – cationic polyelectrolyte. PHMG-HC is related to the biocides with a wide range of antimicrobial action, it provides surfaces that are treated with a long-lasting bactericidal effect (up to 8 months), which is why it is called a unique biocide with prolonged action. However, up to now, the use of PHMG-HC to provide leather materials with antibacterial properties has not been explored.

The research was conducted using the lining leather, impregnated with the dispersed solutions of zeolite and montmorillonite. The modification of leather with PHMG-HC, the substance included in the register of preparations permitted by the EU, was carried out at the stage of after-tanning processes in the production of leather. We propose to use the preparation as a polyfunctional material that fixes the filling and greasing materials in the dermis structure and simultaneously provides it with antibacterial properties.

As a result of research, we established special features of the anti-bacterial properties of leather depending on the treatment of a semi-finished product with the solutions of PHMG-HC at different concentration and the type of mineral filler. It is shown that the examined samples acquire a certain level of biostability when treated with the solution of PHMG-HC at concentration not lower than 2.5 %.

It is determined that the structure of natural minerals and their location in the leather dermis affect the degree of absorption of the biocide by a semi-finished product. It was found that the leather materials, modified with PHMG-HC, exert a pronounced bactericidal effect on the bacteria of the genus Escherichia coli, Pseudomonas aeruginosa, Bacillus subtilis.

Research results demonstrated the possibility of obtaining leather materials with special antibacterial properties when using environmentally safe biocidal preparation (polyhexamethyleneguanidine hydrochloride) and accessible and cheap natural minerals (zeolite, montmorillonite).

**Keywords**: leather, cationic polyelectrolyte, polyhexamethyleneguanidine hydrochloride, zeolite, montmorillonite, biocide, antibacterial properties.

**References**

1. Pekhtasheva, E. L., Nesterov, A. N., Zaykov, H. E., Sof'yna, S. Yu., Deberdeev, R. Ya., Stoyanov, O. V. (2012). Mykrobyolohycheskaya korrozyya y zashchyta ot nee. Vestnyk Kazanskoho tekhnolohycheskoho unyversyteta, 5, 131–134.
2. Pehtasheva, E. L., Neverov, A. N., Sinizin, N. M. (2002). Die Rolle und Nutzung Mikrobiologischer Prozesse im Lebenszyklus von Materialien unter Besonderer Beruck-sichtigund von textilien. Forum ware, 30 (1-4), 73–76.
3. Byopovrezhdenyya y metody otsenky byostoykosty materyalov (1988). Moscow: Nauka, Nauchnyy Sovet po byopovrezhdenyyam, 140.
4. HOST 9.102 ESZKS. Vozdeystvye byolohycheskykh faktorov na tekhnycheskye obekty. Termyny y opredelenyya (1991). Moscow: Yzd-vo standartov, 7.
5. Kozar, O. P., Hrechanyk, Yu. V., Petruvs, B. B., Voznyak, B. (2016). Analysis of theoretical premises for biodeterioration of leather materials and leather products. Technology audit and production reserves, 2 (4 (28)), 42–48. doi: 10.15587/2312-8372.2016.65485
6. Beklemyshev, V. Y., Makhonyn, Y. Y., Maudzhery, U. O. D. (2009). Nanomateryaly y pokrytyya s antymykrobnymy svoystvamy. Nanonauka y nanotekhnolohyy. Entsyklopedyya system zhyzneobespechenyya. UNESCO- EOLSS Encyclopedia. Moscow: YuNESKO, EOLSS, YD MAHYSTR PRESS, 804–831.
7. Osnovni vymohy zakonodavstva YeS do bezpeky ta yakosti tovariv. Available at: http://ukraine-eu.mfa.gov.ua/ua/Ukraine+-+EU+export-import+helpdesk+/Non-tariff+regulation/Загальні+вимоги+ЄС+до+імпортованих+товарів
8. Svetlov, D. A. (2005). Byotsydnye preparaty na osnove proyzvodnykh polyheksametylenhuanydyna. Zhizn' i bezopasnost', 3-4. Avaialble at: http://xn--d1acgbof7bg6f.xn--p1ai/stati/pismo_rukovoditelya_rospotrebnadzora2/
9. Katyonnye PAV. Wikipedia. Available at: https://en.wikipedia.org/wiki/Category: Cationic_surfactants
10. Lysytsya, A. V., Kryvoshyya, P. Yu., Shaturs'kyy, O. Ya. (2010). Vplyv poliheksametylenhuanidynu hidrokhlorydu na plazmatychnu membranu fibroblastiv kuryachykh embrioniv ta na shtuchnu bisharovu lipidnu membranu. Biotekhnolohiya, 3 (2), 56–61.
11. Knunyants, Y. L. (Ed.) (1988). Khymycheskaya entsyklopedyya. Moscow, 623.

12. Khashyrova, S. Yu., Musaev, Yu. Y., Malkanduev, Yu. A., Lyhydov, M. Kh., Musaeva, E. B., Syvov, N. A., Mykytaev, A. K. (2009). Novye hybrydnye nanokompozyty na osnove sloystykh sylykatov y yonohennykh monomer/polymernykh akrylat- y metakrylathuanydynov. Nanotekhnyka, 3, 58–65.
13. Rishennya Komisiyi 2005/344/YeC (2005). Ofitsiynyy visnyk Yevropeys'kykh Spivtovarystv. Available at: http://www.derzhreestr.gov.ua/file/31052
14. Hembytskyy, P. A. (1998). Polymernyy byotsydnyy preparat polyheksametylenhuanydyn. Zaporozh'e: Polyhraf, 44.
15. Dezparitet-info. Available at: http://dezparitet.ru/index/mekhanizm_dejstvija_pgmg/0-190
16. Berri, L. H., Meyson, B. H., Ditrikh, R. V. (1987). Mineralohiya. Moscow: MIR, 603.
17. Danylkovych, A., Mokrousova, O., Zhigotsky, A. (2016). Improvement of the filling and plasticization processes of forming multifunctional leather materials. Eastern-European Journal of Enterprise Technologies, 2 (6 (80)), 23–30. doi: 10.15587/1729-4061.2016.65488
18. Mokrousova, O. R., Kachan, R. V., Kozar', O. P. (2013). Suchasni aspekty pislyadubyl'nykh protsesiv vyrobnytstva shkiry. Tekhnolohiyi ta dyzayn, 4 (9), 1–12.
19. Kozar', O. P., Mokrousova, O. R. (2013). Eco-friendly technologies of leather manufacturing using natural minerals montmorilonite and zeolite. Technology audit and production reserves, 6 (2 (14)), 11–15. doi: 10.15587/2312-8372.2013.19499
20. Kozar, O., Wozniak, B. (2015). Efficiency of environmentally friendly mineral compozitions when manufacturing leather for uppers of spesial shoes. Ecological innovation. Poland: Silesian University of Technology, 208–223.
21. Kozar, O. P., Mokrousova, O. R., Grechanyk, Yu. V. (2014). Evaluation of heat resistance of leather for shoe uppers filled with natural minerals. Proceedings of the 13th Sciense International Conference «MAC ECO SHOES 2014». Cracow, 46–50.
22. Mokrousova, E., Dzyazko, Y., Volfkovich, Y., Nikolskaya, N. (2016). Hierarchical Structure of the Derma Affected by Chemical Treatment and Filling with Bentonite: Diagnostics with a Method of Standard Contact Porosimetry. Nanophysics, Nanophotonics, Surface Studies, and Applications, 277–290. doi: 10.1007/978-3-319-30737-4_23


**DOI**: 10.15587/1729-4061.2017.96120

**ELECTROCHEMICAL WATER SOFTENING IN A DIAPHRAGM ELECTROLYZER (p. 48-55)**

**Viktor Fylypchuk**
National University of Water and Environmental Engineering, Rivne, Ukraine
**ORCID**: http://orcid.org/0000-0001-5763-5398

**Leonid Fylypchuk**
National University of Water and Environmental Engineering, Rivne, Ukraine
**ORCID**: http://orcid.org/0000-0002-5262-6027

The results of studies in electrochemical softening of water in a diaphragm electrolyzer with inert anodes and a porous diaphragm were presented. It was shown that the most significant degree of softening of water at the lowest current and electric power consumptions was observed when water was fed to the anode chambers and moved in parallel flows in the electrode chambers. The total hardness of natural water was reduced to 1.4–1.6 mmole/dm$^3$, alkalinity to 3.8–4.3 mmole/dm$^3$, pH by 0.3–0.6 and acidity practically did not change. The recommended process scheme for water softening involves parallel movement of catholyte and anolyte streams in the electrolyzer at a ratio of their consumptions (7–8):(3–2) and their separate extraction from the electrode chambers. Catholyte is filtered to remove insoluble hardness salts and mixed with anolyte. The degree of water softening is regulated only by changing the strength of direct current applied to the electrodes. The technology makes it possible to completely abandon the use of chemical reagents, simultaneously stabilize and disinfect softened water and avoid secondary contamination of water with chemicals. The design of an industrial monopolar electrolyzer with an inactive diaphragm for electrochemical change of pH and Eh was developed. The electrolyzer features a solid anode and a perforated cathode or perforated electrodes closely pressed against the diaphragm. The softening technology is advisable to use for local water preparation for production operations and before softening hard water with ion-exchange filters or electrodialyzers. The developed technology of water softening and purification has been introduced at a number of enterprises in Slovakia and Ukraine, in particular, for industrial water treatment in galvanic plants and flour mills.

**Keywords**: water softening, diaphragm electrolyzer, active reaction, oxidation-reduction potential.

**Refrences**


1. Frog, B., Pervov, A. (2014). Vodopodgotovka [Water conditioning]. Moscow: Publishers Association building universities, 512.
2. Van der Bruggen, B., Goossens, H., Everard, P. A., Stemgee, K., Rogge, W. (2009). Cost-benefit analysis of central softening for production of drinking water. Journal of Environmental Management, 91 (2), 541–549. doi: 10.1016/j.jenvman.2009.09.024
3. Cuda, P., Pospisil, P., Tenglerova, J. (2006). Reverse osmosis in water treatment for boilers. Desalination, 198 (1-3), 41–46. doi: 10.1016/j.desal.2006.09.007
4. Nanda, D., Tung, K.-L., Hsiung, C.-C., Chuang, C.-J., Ruaan, R.-C., Chiang, Y.-C. et. al. (2008). Effect of solution chemistry on water softening using charged nanofiltration membranes. Desalination, 234 (1-3), 344–353. doi: 10.1016/j.desal.2007.09.103
5. Entezari, M., Tahmasbi, M. (2009). Water softening by combination of ultrasound and ion exchange. Ultrasonics Sonochemistry, 16 (3), 356–360. doi: 10.1016/j.ultsonch.2008.09.008
6. Rogov, V. M., Filipchuk, V. L. (1989). Elektrokhimicheskaya tekhnologiya izmeneniya svoystv vody [The electrochemical technology is changing the properties of water]. Lviv: Vishcha School, 127.
7. Gabrielli, C., Maurin, G., Francy-Chausson, H., Thery, P., Tran, T. T. M., Tlili, M. (2006). Electrochemical water softening: principle and application. Desalination, 201 (1-3), 150–163. doi: 10.1016/j.desal.2006.02.012
8. Zhi, S., Zhang, S. (2014). A novel combined electrochemical system for hardness removal. Desalination, 349, 68–72. doi: 10.1016/j.desal.2014.06.023
9. Malakootian, M., Mansoorian, H. J., Moosazadeh, M. (2010). Performance evaluation of electrocoagulation process using iron-rod electrodes for removing hardness from drinking water. Desalination, 255 (1-3), 67–71. doi: 10.1016/j.desal.2010.01.015
10. Zeppenfeld, K. (2011). Electrochemical removal of calcium and magnesium ions from aqueous solutions. Desalination, 277 (1-3), 99–105. doi: 10.1016/j.desal.2011.04.005
11. Hasson, D., Shemer, H., Semiat, R. (2015). Removal of scale-forming ions by a novel cation-exchange electrochemical system – A review. Desalination and Water Treatment, 57 (48-49), 23147–23161. doi: 10.1080/19443994.2015.1098806
12. Park, J.-S., Song, J.-H., Yeon, K.-H., Moon, S.-H. (2007). Removal of hardness ions from tap water using electromembrane processes. Desalination, 202 (1-3), 1–8. doi: 10.1016/j.desal.2005.12.031

13. Seo, S.-J., Jeon, H., Lee, J. K., Kim, G.-Y., Park, D., Nojima, H. et. al. (2010). Investigation on removal of hardness ions by capacitive deionization (CDI) for water softening applications. Water Research, 44 (7), 2267–2275. doi: 10.1016/j.watres.2009.10.020
14. Zaslavschi, I., Shemer, H., Hasson, D., Semiat, R. (2013). Electrochemical $CaCO_3$ scale removal with a bipolar membrane system. Journal of Membrane Science, 445, 88–95. doi: 10.1016/j.memsci.2013.05.042
15. Demidova, Y. M., Shinkevich, E. O., Laptev, A. G. (2010). Use of a resource-saving technology in water treatment systems. Thermal Engineering, 57 (8), 657–661. doi: 10.1134/s0040601510080057
16. Bagrii, V. A., Chebotaryova, R. D., Bashtan, S. Y., Remez, S. V., Goncharuk, V. V. (2008). Softening of calcium-hydrocarbonate water in a flow-through electrolyzer with a filtrating cartridge. Journal of Water Chemistry and Technology, 30 (2), 100–104. doi: 10.3103/s1063455x08020069
17. Hasson, D., Sidorenko, G., Semiat, R. (2010). Calcium carbonate hardness removal by a novel electrochemical seeds system. Desalination, 263 (1-3), 285–289. doi: 10.1016/j.desal.2010.06.036
18. Zito, R. (2011). Electrochemical Water Processing. John Wiley & Sons, 314. doi: 10.1002/9781118104675
19. Filipchuk, V. L., Filipchuk, L. V. (2016). Zastosuvanya gaziv dlya regulyuvannya okisno-vidnovnih vlastivostey vody [The uze of gases for regulation redox properties of water]. Journal of Engineering Academy of Ukraine, 1, 178–183.


**DOI**: 10.15587/1729-4061.2017.98675

## DEVELOPMENT OF THE MATHEMATICAL MODEL OF THE BIOTREATMENT PROCESS OF WATER-SOLUBLE GASEOUS EMISSIONS (p. 56-62)


**Anna Bakhareva**
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0003-0765-9943

**Oleksii Shestopalov**
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0001-6268-8638

**Olesya Filenko**
National Technical University
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0002-0277-6633

**Tetiana Novozhylova**
National technical university
«Kharkiv Polytechnic Institute», Kharkiv, Ukraine
**ORCID**: http://orcid.org/0000-0003-2551-6954

**Boris Kobilyansky**
Teaching and Research Professional Pedagogical Institute of Ukrainian Engineering and Pedagogical Academy, Bakhmut, Ukraine
**ORCID**: http://orcid.org/0000-0001-6835-9042



In the experimental research, the kinetic characteristics of hydrogen sulfide, sulfur dioxide and ammonia biooxidation were determined. It was found that the hydrogen sulfide and sulfur dioxide oxidation rates varied from 12 mg/g of biomass per hour in the region of the minimum pollution concentrations to the maximum value of 40 mg/g·h. As for ammonia, the variation range was 1.5–5 mg/g·h, respectively. The analytical description of the dependence of the specific degradation rate of pollutants on their concentration was proposed. The obtained quantitative values and variation nature of the specific oxidation rate prove the technological possibility of using the trickle-bed bioreactor for treatment of water-solvable gaseous emissions.

Based on the experimental research, the mathematical description of the non-stationary biooxidation process of water-soluble gaseous hydrogen sulfide, sulfur dioxide and ammonia was developed. The developed mathematical model is based on the mass balance in the trickling layer of the bioreactor in the course of absorption and biodegradation processes. The analytical dependencies consider the emergence of dynamic balance between the harmful matter arrival intensity and oxidation. The state of dynamic balance determines the boundary of the bioreactor efficiency. The results allow evidence-based calculations of the hydrogen sulfide, sulfur dioxide and ammonia biotreatment process in the trickle-bed bioreactor.


**Keywords**: emission treatment, biotreatment process, hydrogen sulfide, sulfur dioxide, bioreactor.

**Refrences**


1. Kennes, C., Rene, E. R., Veiga, M. C. (2009). Bioprocesses for air pollution control. Journal of Chemical Technology & Biotechnology, 84 (10), 1419–1436. doi: 10.1002/jctb.2216
2. Shestopalov, O. V., Pitak, I. V. (2014). Analysis of existent processes and devices of bioscrubbing gas emissions. Technology audit and production reserves, 3 (5 (17)), 49–52. doi: 10.15587/2312-8372.2014.25373
3. Chan, W.-C., Peng, K.-H. (2008). Biodegradation of Methyl Ethyl Ketone and Methyl Isopropyl Ketone in a Composite Bead Biofilter. Engineering in Life Sciences, 8 (2), 167–174. doi: 10.1002/elsc.200720231
4. Seedorf, J. (2013). Biological exhaust air treatment systems as a potential microbial risk for farm animals assessed with a computer simulation. Journal of the Science of Food and Agriculture, 93 (12), 3129–3132. doi: 10.1002/jsfa.6106
5. Iranpour, R., Cox, H. H. J., Deshusses, M. A., Schroeder, E. D. (2005). Literature review of air pollution control biofilters and biotrickling filters for odor and volatile organic compound removal. Environmental Progress, 24 (3), 254–267. doi: 10.1002/ep.10077
6. Mohammad, B. T., Veiga, M. C., Kennes, C. (2007). Mesophilic and thermophilic biotreatment of BTEX-polluted air in reactors. Biotechnology and Bioengineering, 97 (6), 1423–1438. doi: 10.1002/bit.21350
7. Rojo, N., Munoz, R., Gallastegui, G., Barona, A., Gurtubay, L., Prenafeta-Boldu, F. X., Elias, A. (2012). Carbon disulfide biofiltration: Influence of the accumulation of biodegradation products on biomass development. Journal of Chemical Technology & Biotechnology, 87 (6), 764–771. doi: 10.1002/jctb.3743
8. Malhautier, L., Cariou, S., Legrand, P., Touraud, E., Geiger, P., Fanlo, J.-L. (2014). Treatment of complex gaseous emissions emitted by a rendering facility using a semi-industrial biofilter. Journal of Chemical Technology & Biotechnology, 91 (2), 426–430. doi: 10.1002/jctb.4593
9. Song, T., Yang, C., Zeng, G., Yu, G., Xu, C. (2012). Effect of surfactant on styrene removal from waste gas streams in biotrickling filters. Journal of Chemical Technology & Biotechnology, 87 (6), 785–790. doi: 10.1002/jctb.3717
10. Engesser, K.-H., Plaggemeier, T. (2008). Microbiological Aspects of Biological Waste Gas Purification. Biotechnology Set, 275–302. doi: 10.1002/9783527620999.ch12n
11. Nelson, M., Bohn, H. L. (2011). Soil-Based Biofiltration for Air Purification: Potentials for Environmental and Space LifeSupport Application. Journal of Environmental Protection, 02 (08), 1084–1094. doi: 10.4236/jep.2011.28125

12. Rizzolo, J. A., Woiciechowski, A. L., dos Santos, V. C. C., Soares, M., Páca, J., Soccol, C. R. (2012). Biofiltration of increasing concentration gasoline vapors with different ethanol proportions. Journal of Chemical Technology & Biotechnology, 87 (6), 791–796. doi: 10.1002/jctb.3780
13. Zagorskis, A., Vaiskunaite, R. (2014). An Investigation on the Efficiency of Air Purification Using a Biofilter with Activated Bed of Different Origin. Chemical and Process Engineering, 35 (4). doi: 10.2478/cpe-2014-0033
14. Gonzalez-Sanchez, A., Arellano-Garcia, L., Bonilla-Blancas, W., Baquerizo, G., Hernandez, S., Gabriel, D., Revah, S. (2014). Kinetic Characterization by Respirometry of Volatile Organic Compound-Degrading Biofilms from Gas-Phase Biological Filters. Industrial & Engineering Chemistry Research, 53 (50), 19405–19415. doi: 10.1021/ie503327f
15. Shareefdeen, Z., Aidan, A., Ahmed, W., Khatri, M. B., Islam, M., Lecheheb, R., Shams, F. (2010). Hydrogen Sulphide Removal Using a Novel Biofilter Media. World Academy of Science, Engineering and Technology, 62, 13–16.
16. Shareefdeen, Z. M., Ahmed, W., Aidan, A. (2011). Kinetics and Modeling of H2S Removal in a Novel Biofilter. Advances in Chemical Engineering and Science, 01 (02), 72–76. doi: 10.4236/aces.2011.12012
17. Bonilla-Blancas, W., Mora, M., Revah, S., Baeza, J. A., Lafuente, J., Gamisans, X. et. al. (2015). Application of a novel respirometric methodology to characterize mass transfer and activity of $H_2S$-oxidizing biofilms in biotrickling filter beds. Biochemical Engineering Journal, 99, 24–34. doi: 10.1016/j.bej.2015.02.030
18. Bakhareva, A., Shestopalov, O., Filenko, O., Kobilyansky, B. (2016). Development of universal model of kinetics of bioremediation stationary process with substrate inhibition. Eastern-European Journal of Enterprise Technologies, 2 (10 (80)), 19–26. doi: 10.15587/1729-4061.2016.65036
19. Bakhareva, A., Shestopalov, O., Filenko, O., Tykhomyrova, T. (2015). Development of a mathematical model of the process of biological treatment of gaseous emissions. Eastern-European Journal of Enterprise Technologies, 6 (6 (78)), 53–61. doi: 10.15587/1729-4061.2015.56220
20. Bakhareva, A., Shestopalov, O., Filenko, O., Tykhomyrova, T. (2016). Development of a mathematical model of the process of biological treatment of gaseous emissions. Eastern-European Journal of Enterprise Technologies, 1 (10 (79)), 4–10. doi: 10.15587/1729-4061.2016.59508
21. Bahareva, A. Yu., Shestopalov, O. V., Semenov, E. O., Bukatenko, N. O. (2015). Macrokinetic mathematical model development of biological treatment process of gasiform emissions. ScienceRise, 2 (2 (7)), 12–15. doi: 10.15587/2313-8416.2015.37057


---

**DOI**: 10.15587/1729-4061.2017.98712

**MATHEMATICAL MODELING AND COMPUTER SIMULATION OF THE FILTRATION PROCESSES IN EARTH DAMS (p. 63-69)**

**Natalia Ivanchuk**
National University of Water and Environmental Engineering, Rivne, Ukraine
**ORCID**: http://orcid.org/0000-0002-7170-7068

**Petro Martynyuk**
National University of Water and Environmental Engineering, Rivne, Ukraine
**ORCID**: http://orcid.org/0000-0002-2750-2508

**Tatiana Tsvetkova**
National University of Water and Environmental Engineering, Rivne, Ukraine
**ORCID**: http://orcid.org/0000-0003-4356-7368

**Olga Michuta**
National University of Water and Environmental Engineering, Rivne, Ukraine
**ORCID**: http://orcid.org/0000-0003-2886-0662

We built a mathematical model of the filtration consolidation of the body of an earth dam with engineering inclusions and erosion zone in a two-dimensional setting. It considers the presence of a damaged conduit in the body of a dam. We also took into account the impact of anthropogenic factors: temperature and the concentration of salts, subsidence of the upper boundary and the displacement of internal points in the region of dam over time. The existence of erosion zone (as a result of damage to the conduit) is considered. Taking into account the erosion zone exerts a significant effect on the overall picture of filtration processes occurring in the body of a dam. Erosion zone has the largest impact on the distribution of excess heads and their gradients. We developed a software application to automate the calculation of numerical solution of a boundary problem using the method of radial basis functions that make it possible to conduct numerical experiments by changing the input parameters and the form, as well as represent results of these experiments in the form of charts and numerical data according to each temporal layer. The software application was developed in the integrated programming environment Microsoft Visual Studio 2008 in the language C#. The impact of the existence of a conduit, erosion zone, temperature and the concentration of salts in the body of a dam was explored at different temporal layers. The distribution of all the desired functions and their impact can be displayed graphically. A series of numerical experiments were performed and their analysis conducted. It is shown as a result that the existence of damage in a conduit in the body of a dam leads to the formation of erosion zone.

This, in turn, leads to the gradual filtration destruction of soil material of the dam and its possible complete destruction. The results obtained might help to prevent and to evaluate the consequences of possible accidents without conducting field experiments, and, consequently, to save resources and time.

**Keywords**: hydropower engineering, problem of filtration consolidation, osmotic phenomena, free surface, object-oriented programming.

**Refrences**


1. Foster, M. (2000). Use of event trees to estimate the probability of failure of embankment dams by internal erosion and piping. 20th Congress on Large Dams. Beijing, 237–259.
2. Malik, L. K. (2009). Emergency situations related to hydrotechnical construction. Hydrotechnical construction, 12, 2–16.
3. Vlasyuk, A., Martyniuk, P. (2010). Numerical solution of problems of filtration consolidation and destruction of soils in terms of heat-mass transfer by radial basis functions method. Rivne: NUWMNRU, 277.
4. Sellmeijer, J. B. (2006). Numerical computation of seepage erosion below dams (piping). Proc. 3rd Int.Conf.Scour and Erosion. Amsterdam, 6.
5. Vlasyuk, A. P., Martynyuk, P. N. (2012). Contact erosion and filtration consolidation of soils under conditions of heat-salt transfer. Mathematical modeling, 24 (11), 97–112.
6. Vlasyuk, A. P., Martynyuk, P. M. (2010). Numerical solution of three-dimensional problems of filtration consolidation with regard for the influence of technogenic factors by the method of radial

basis functions. Journal of Mathematical Sciences, 171 (5), 632–648. doi: 10.1007/s10958-010-0163-z

7. Vlasyuk, A. P., Tsvetkova, T. P. (2015). Mathematical Simulation of the Transport of Salt in the Case of Filtration and Moisture Transfer in Saturated-Unsaturated Soils in a Moistening Regime. Journal of Engineering Physics and Thermophysics, 88 (5), 1062–1073. doi: 10.1007/s10891-015-1285-4
8. Sergienko, I., Skopetsky, V., Deineka, V. (1991). Mathematical modeling and study of processes in inhomogeneous media. Kyiv: Naukova Dumka, 432.
9. Kutia, T. (2014). Mathematical modeling of wetting of the soil on the slope in conditions salt transfer. Visnyk KNU. Ser.: Mathematical Modeling. Information Technology. Automated control systems, 1105, 99–110.
10. Martynyuk, P. M. (2015). Existence and uniqueness of a solution of the problem with free boundary in the theory of filtration consolidation of soils with regard for the influence of technogenic factors. Journal of Mathematical Sciences, 207 (1), 59–73. doi: 10.1007/s10958-015-2355-z
11. Martyniuk, P. (2014). Solution of boundary value problems for systems of quasi-linear parabolic equations by grid and meshfree numerical methods. Siberian Electronic Mathematical Reports, 11, 476–493.
12. Tolstyh, A., Shirobokov, D. (2005). Meshless method based on radial basis functions. Computational Mathematics and Mathematical Physics Journal, 45 (8), 1447–1454.
13. Biazar, J., Asadi, M. (2015). Galerkin RBF for Integro-Differential Equations. British Journal of Mathematics & Computer Science, 11 (2), 1–9. doi: 10.9734/bjmcs/2015/19265
14. Franke, C., Schaback, R. (1998). Solving partial differential equations by collocation using radial basis functions. Applied Mathematics and Computation, 93 (1), 73–82. doi: 10.1016/s0096-3003(97)10104-7
15. Giesl, P., Wendland, H. (2007). Meshless Collocation: Error Estimates with Application to Dynamical Systems. SIAM Journal on Numerical Analysis, 45 (4), 1723–1741. doi: 10.1137/060658813
16. Lukner, L., Shestakov, V. (1976). Modeling of geofiltration. Moscow: Nedra, 407.

**DOI**: 10.15587/1729-4061.2017.97256

## DEVELOPMENT OF TECHNOLOGY FOR RECYCLING THE LIQUID IRON-CONTAINING WASTES OF STEEL SURFACE ETCHING (p. 70-77)

**Mykola Yatskov**
National University of Water and Environmental Engineering, Rivne, Ukraine
**ORCID**: http://orcid.org/0000-0002-6231-6583

**Natalia Korchyk**
National University of Water and Environmental Engineering, Rivne, Ukraine
**ORCID**: http://orcid.org/0000-0003-4919-6510

**Nadia Budenkova**
National University of Water and Environmental Engineering, Rivne, Ukraine
**ORCID**: http://orcid.org/0000-0003-2176-3405

**Svitlana Kyrylyuk**
Technical College National University of Water Management and Nature, Rivne, Ukraine
**ORCID**: http://orcid.org/0000-0002-1030-4548

**Oleg Prorok**
National University of Water and Environmental Engineering, Rivne, Ukraine
**ORCID**: http://orcid.org/0000-0001-9670-9396

Results of the conducted theoretical and practical research into processes of recycling the iron-containing wastes of steel surfaces etching are presented, namely, regeneration and utilization of used-up etching solutions and purification of wash water. Based on the results of research, new technological approaches to waste recycling with the view of minimizing their discharge into the environment and reducing costs of an enterprise were substantiated and practically tested.

The existing technologies for recycling the iron-containing wastes of steel surfaces etching require updating in order to minimize their discharge into environment and to reduce the expenditures of an enterprise. It is known that in the theoretical approach to the concentrated solutions of electrolytes, so many correction coefficients were introduced to the theory of calculations that the results of calculations lose their physical essence. Therefore, for the concentrated solutions, it is necessary to determine the basic parameters experimentally.

After exploring the technology of wash water purification, it was established that the most effective way is treatment with lime with flocculant (brand Zetag 8180) and filtering through a filter with polystyrene foam. A part of the treated water was passed through a reverse osmosis system, which, at subsequent mixing with the main part of the flow, makes it possible to obtain water of the "Technical water" category II quality.

In order to develop a technology for the regeneration of used-up etching solutions, we conducted research into redox properties of UES both with $H_2O_2$ and without it at different pH values. The optimal scheme of treatment is the one that includes alkalization with a 40 % solution of $Ca(OH)_2$ until achieving pH=4.2, and treatment with a hydrogen peroxide solution.

The technology of recycling of used-up etching solutions with the application of UES as a chemical reagent makes it possible:

1) with the alkalization, to provide optimal extraction of zinc from complex compounds, which also increases at a co-sedimentation of zinc and iron;

2) to provide optimal conditions for the oxidation of organic compounds in alkaline wastewater after degreasing operations.

**Keywords**: liquid wastes, regeneration, hydration, used-up etching solutions, redox properties, wash water.

**Refrences**

1. Korchyk, N. M., Bielikova, S. V. (2012). Ochystka y reheneratsyia stochnykh vod halvanycheskoho proyzvodstva. Ekolohiya plus, 6 (33), 10–13.
2. Denzanov, H. O., Petruk, V. H., Tkhor, I. I. (2008). Pat. No. 35548 UA. Sposib reheneratsiyi i utylizatsiyi vidprats'ovanykh travyl'nykh rozchyniv. MKP S01G 3/00. No. U200804873; declareted: 15.04.2008; published: 25.09.2008, Bul. No. 18, 10.
3. Nester, A. A., Korchyk, N. M., Baran, B. A. (2008). Stichni vody pidpryiemstv ta yikh ochynnia. Khmelnytsk: KhNU, 171.
4. Uretskyi, E. A. (2007). Resursosberehaiushchye tekhnolohyy v vodnom khoziaistve promyshlennykh predpryiatyi. Brest: BrHTU, 396.
5. Vasylenko, I. A., Pivovarov, O. A. (2016). Zalizooksydni pihmenty. Syntez, modyfikuvannia, vykorystannia u riznykh haluziakh nauky i tekhniky. Dnipropetrovsk: Aktsent PP, 217.
6. Vasylenko, I. A., Kuman'ov, S. O. (2011). Pat. No. 102154 UA. Sposib utylizatsiyi kyslykh zalizovmisnykh rozchyniv. MKP S09S 1/22. No. a201112825; declareted: 01.11.2011; published: 10.06.2013, Bul. No. 11, 6.
7. Kruhlykov, S. S., Turaiev, D. Yu., Buzykova, A. M. (2009). Reheneratsyia rastvora travlenyia medy v proyzvodstve pechatnykh plat metodom membrannoho elektrolyza. Halvanotekhnyka i obrabotka poverkhnosty, 1, 40–48.
8. Mel'nykov, B. I., Vasylenko, I. A., Vakal, S. V., Zolotar'ov, O. Ye. (2009). Pat. No. 91164 UA. Sposib oderzhannya zalizooksydnoho pihmentu. MKP S09S 1/22, 1/24. No. 200907856; declareted: 27.07.2009; published: 26.06.2010, Bul. No. 12, 8.

9. Aydin, A. A., Aydin, A. (2014). Development of an immobilization process for heavy metal containing galvanic solid wastes by use of sodium silicate and sodium tetraborate. Journal of Hazardous Materials, 270, 35–44. doi: 10.1016/j.jhazmat.2013.12.017
10. Sharma, V. K., Yngard, R. A., Cabelli, D. E., Clayton Baum, J. (2008). Ferrate (VI) and ferrate (V) oxidation of cyanide, thiocyanate, and copper (I) cyanide. Radiation Physics and Chemistry, 77 (6), 761–767. doi: 10.1016/j.radphyschem.2007.11.004
11. Vasylenko, I. A., Kuman'ov, S. O. (2011). Pat. No. 100944 UA. Sposib oderzhannya zhovtoho zalizooksydnoho pihmentu. MKP S09S 1/22, 1/24; S01G 45/02. No. 201112246; declareted: 19.10.2011; published: 11.02.2013, Bul. No. 3, 12.
12. Vasylenko, I. A., Chyvanov, V. D., Bordunova, O. D. (2011). Pat. No. 99538 UA. Sposib oderzhannya chornoho zalizooksydnoho pihmentu. MKP S09S 1/22, 1/24, 1/62, 3/06. No. 201101341; declareted: 07.02.2011; published: 27.08.2012, Bul. No. 16, 8.
13. Natsional'na dopovid' pro stan navkolyshn'oho pryrodnoho seredovyshcha v Ukrayini: za danymy Ministerstva okhorony navkolyshn'oho pryrodnoho seredovyshcha Ukrayiny za 2007–2009 rr. Ministerstvo ekolohiyi ta pryrodnykh resursiv Ukrayiny. Available at: http://www.menr.gov.ua/
14. Zapolskyi, A. K. (2005). Fizyko-khimichni osnovy tekhnolohii ochyshchennia stichnykh vod. Kyiv: Vyshcha shkola, 671.
15. Korchyk, N. M., Yatskov, M. V., Byelikova, S. V. (2012). Pat. No. 76053A UA. Sposib ochyshchennya stichnykh vod hal'vanichnoho vyrobnytstva. MKP S02F 9/04. No. u201206086; declareted: 21.05.2012; published: 25.12.2012, Bul. No. 24, 11.
16. Fedushchak, N. K., Bidnychenko, Yu. D., Kramarenko, S. Yu. (2012). Analitychna khimiia. Vinnytsya: Nova knyha, 477.