INTRODUCTION

The amount of rinse waters of plating plants in the engineering works makes 30-50% of the total amount of wastewaters (Fu & Wang, 2011). Besides, significant part of the chemical agents used for the plating purposes being washed off the plated parts flows into the sewage system. Such chemical agents are not only toxic, but deficient. For example, rinse water contains about 1% of the plating bath concentration (Gayathri & Senthil Kumar, 2010).

There are many methods for the removal of nonferrous metals from such waters, including reagent method (Mirbagheri & Hosseini, 2005), biological (Mary Mangaiyarkarasi et al., 2011, Hirpara et al., 2011), electrocoagulation (Adhoum et al., 2004, Verma et al. 2013), baromembrane (Korus & Loska, 2009, Kozlowski & Walkowiak, 2002, Wang et al., 2007), electrolydysis (Marder et al., 2004, Benvenuti et al., 2014), sorption (Arslan & Pehlivian, 2007, Gode et al., 2006), ion-exchange methods (Xing et al., 2007) and combined ones (ex. ion-exchange resins and sorbents (Aleksueva et al., 2007), electrodialysis (ED) and ion-exchange (Alvarado et al., 2009), electroflotation and electrocoagulation (Gao et al., 2005), complexation and ultrafiltration (Petrov & Nenov, 2004), liquid membranes and ED (Sadyrbaeva, 2016), ED after sedimentation under the action of chemical agents (Peng et al., 2005). Some toxic metals may be sedimented from soluble compounds by means of correction of pH, but not for chromium, as chromium (IV) is soluble in the wide range of pH (Barakat, 2011).

The analysis of the scientific writings shows that in spite of the diversity of methods, none may be considered universal, although the ED method has some prospects for chromium-containing water treatment (demineralization). Previously, ED was used mainly for desalination (sea water, mine waters) (Scott, 1995), but further this method
became important in minimization of impact of toxic productions on the environment (Judd & Jefferson, 2003). The ED method is a membrane process of separation of substances. It is based on the phenomenon of transfer of electrolyte ions though ion-selective membrane under influence of electric field (Strathmann, 2004). Treatment of electrolyte solutions provided in the electrodialysis apparatuses (EDA) (Figure 1).

The ED method has some advantages: no reagent requirements, lack of phase transitions of solution and low operative costs, simplicity of device design, recycling of about 60% of water, ability to utilize valuable components, ability to treat up to maximum permissible concentration. Moreover, the costs of power used in treatment of solution are lower than those connected with use of the chemical methods (Gurreri et al., 2020).

The main element of the EDA includes ion-exchange membranes (IEM). They are made by mixing of ion-exchange resin powder and polyethylene powder as a binder followed by hot-roll-forging into sheets with further reinforcing thereof or without reinforcement. Mainly cation-exchange membranes have sulfonate groups, whereas anion-exchange membranes have quaternary ammonium bases (Gurreri et al., 2020).

IEM are selected for use in concrete process taking into consideration their properties. The physicochemical properties of the membranes depend to a large extent on their composition, nature and production technology.

An ideal membrane should have the following properties: low moisture content, weak swelling characteristic, high conductivity and selectiveness, chemical stability and mechanic solidity which provide long-term operation of membranes. Exploration of the new methods and materials, improvement of the existing methods aiming to produce high quality membranes goes on continuously (Sardohan et al., 2010, Santiago et al., 2010, Melnikov & Shkirskaya, 2019). Leading companies operating in this sphere include Astom. Corp. JP. (NEOSEPTA, Japan) (San Román et al., 2012), Du Pont (Nafion, USA) (Mauritz & Moore, 2004), Mega Cz. (Ralex, Czech Republic) (Noubli et al., 2020). The whole range of currently produced membranes allows providing demineralization and concentration of electrolyte solutions (Barakat et al., 2011, Serdiuk et al., 2018). The studies for creation of new polymer matrixes for both homogeneous and heterogeneous IEM are being increasingly improved. Since 1962, Du Pont has held the patent for production of the sulfonic cation membrane Nafion based on fluorocarbon matrix. From 1970s perfluorated matrices have been used in the chlor-alkali media.

In the research by Dalla Costa et al. (2002) the membranes Nafion 450 (Du Pont de Nemours and Co.) and Selemon AMP (Asahi Glass Co.) were used in the process of electrodialytic removal of metal ions (Zn, Ni, Cu, Al) from the industrial waters of metal processing. The anion-exchange membranes produced from the mixture of polystyrene and polyaniline were used for purification of the chromium ions-containing industrial waters of processing of leather and metals (Moura et al., 2012). The process of removal of chromium ions

![Figure 1. Scheme of electrodialysis (Khan et al., 2016)](image-url)
and selective transportation of Cr (VI) through the membranes containing 5-(4-phenoxophenyl)-6H-1,3,4-thiadiazin-2-amine was researched by the authors (Saf et al., 2011). According to the article (Nataraj et al., 2007) they used the experimental EDA in the research regarding the dependence of chromium ions removal effectiveness on such parameters, as the applied potential, pH, initial concentration of solution, and flow rate. The important data were obtained for the low initial concentration (10 ppm). The removal of Cr(VI) mainly becomes problematic due to the instability of parameters of anion-exchange membranes during the electrodialysis process, namely, increase of membrane resistance and concentration polarization, i.e. concentration of concentrate may limit electrodialysis process.

In the apparatus designed by the authors, the heterogeneous membranes produced by Ltd. “Innovative Enterprise Shchekinoazot” (Shchekino, Russia) were used. This company produces various types of heterogeneous membranes by small parcels to orders. It is the only manufacturer of monopolar heterogeneous ion exchange membranes of MK-40, MK-40L, MA-41, MA-41L brands in Russia. Previously, these membranes were actively used in EDA for water desalination, but in the last years, the apparatuses produced in Shchekino enterprise have operated in the milk processing plants. MK-40 and MA-40 differ from the Japanese and American counterparts due to thickness (0.45–0.60 mm), although in ED of dissolved solutions, the share of voltage drop caused with thickness of the material is insignificant. Due to sufficiently high selectiveness, high mechanic stability and ability of restoration of the initial parameters after drying, they are used for EDA in desalination processes (Sarapulova et al., 2019, Gubari et al., 2021).

Taking into consideration that the membranes used in ED are easily “poisoned” in the corrosive media, the main aim of the conducted study included selection of the ion-exchange membranes used in desalination and concentration of chromium-containing solutions with the ED method, for extension of their life.

**RESEARCH OBJECTS AND METHODS**

They were processed with the electrodialysis apparatus (EDA) designed by the authors and supplied with the heterogeneous membranes produced by Ltd. «Innovative Enterprise Shchekinoazot” (Shchekino, Russia). Initially, EDA was supplied with the MK-40 and MA-40 membranes, then they were replaced with MK-40L and MA-41L. The main properties of commercial membranes MK-40 and MK-40 are collected in Table 1.

MK-40 is a composite of polyethylene and cation-exchange resin received by copolymerization of styrene and divinylbenzene with further introduction of sulfonic group. MA-40 is a composite based on the EDE-10P resin received by polycondensation of epichlorohydrin and polyethylene polyamine. MA-41 is a composite of polyethylene and anion-exchange resin which is obtained by amination of the polymer received by copolymerization of styrene and divinylbenzene. The membranes are reinforced with nylon fabric.

| Properties of membranes | MK-40 | MK-40 L | MA-40 | MA-41L |
|-------------------------|-------|---------|-------|--------|
| Ion.exchange group      | SO₃H | SO₃H | ≡N; ≡N; ≡N; | ≡N; ≡N; N(CH₃)₃ |
| Grade of ion exchanger  | KU-2  | KU-2   | EDE-10P | AB-17 |
| Content of ion exchanger| 65%   | 65%    | 55%    | 65%    |
| Basic binder on base    | polyethylene | nylon | nylon | nylon |
| Fitting fabrics         | nylon | lavsan | nylon | lavsan |
| Length x Width, mm      | 1420 x 450 |
| Thickness, mm           | 0.3-0.4 | 0.3-0.4 | 0.3-0.4 | 0.3-0.4 |
| Transparency at fracture, MPa, not less than | 11.9 | 10.6 | 12.7 | 11.0 |
| Surface resistance, Ohm·cm², not more than | 10.0 | 14.0 | 12.0 | 20.0 |
| Transfer number, fractions, not less than | 0.98 | 0.96 | 0.94 | 0.96 |
or lavsan fabric. The membranes reinforced with lavsan fabric (MK-40L and MA-41 L) are notable for their chemical stability. For the purpose of determination of the technological parameters of ED process of desalination and concentration of the chromate-containing solution, the experimental device produced in the Institute engineering workshop was used (Figure 2).

The chromate-containing solution was pumped from the circulation reservoir into the desalination chambers of the apparatus, it was not delivered to the concentration chambers. The concentrate originated in these chambers with the hydrated ions and the water molecules transited by means of electroosmosis and aggregated in the separate concentration reservoir. The electrodialysis device was operated in the circulation mode, i.e. after coming out of the apparatus, the dialyzate passed to the circulation reservoir and circulated there up to desalination (Figure 2). For the experiment purposes, the real effluents of the washing bath of plating shop of the local plant were used.

After each cycle of desalination, so-called repolarization of the hydraulic flows and electrodes was carried out. In the case of direct polarity, the lower electrodes of the apparatus were the cathodes, while the upper ones – the anodes. After repolarization, the lower electrodes were the anodes, whereas the upper ones – the cathodes. Under these conditions, the dialyzate chambers became the concentration ones and vice versa (Figure 3).

Operation package of EDA was equipped with MK-40 and MA-40 IEM (25 pairs of membranes in the apparatus, total area of one kind of membrane was 1.3 m²) with the liquid flow separation frames (0.9 mm height), with the corrugated mash-turbulators and platinized titan electrodes. The membrane package was assembled in the chambers as per the liquid flow distribution parallel circuit. Electrode chambers operate as the working chambers, i.e. in one polarity they operate as dialyzate chambers, but in the other one – as concentration chambers. In the case of necessity, the electrode chambers were washed with sodium sulfate solution.

Determination of the hydraulic properties of the device

The amount of the solution passing through the electrodialysis device was determined under conditions of the direct (lower electrode is a cathode, the upper one is an anode) and reverse polarity. For this purpose, the solution consumption for each polarity was measured at the outlet from the dialyzate chambers – $Q_d$, providing that the pump was on and the valve located at the inlet of the solution pipe leading to the dialyzate chambers was completely open; simultaneously, the mechanic overflow of the solution from the dialyzate pipe to the concentrate chambers was measured – $Q_c$. Maximum capacity of the electrodialysis device was calculated with the following formula:

$$ V = \frac{Q}{S \cdot n} $$

where: $S$ – area of cress section of the dialyzate chamber; $n$ – quantity of the dialyzate chambers ($n = 25$)
Determinations of the technological parameters of the process

The process implemented in the electrodialysis device operating in the mode of circulation and direct current. During the process, the change of concentration in the reservoir was measured. Balancing of the membranes lasted up to achievement of the constant concentration in the reservoir.

The experiment was carried out in the above hydraulic mode, under the conditions of chromate ions-contained solution \((C_{\text{initial}} = 50\, \text{mg/L})\) and voltage \((U = 250\, \text{V})\). The following parameters were determined:

- desalination cycle time, min;
- temperature of the solution in the reservoir, \(C^\circ\);
- consumption of the solution in the dialyzate \((Q_d, \text{L/h})\) and in the concentrate \((Q_c, \text{L/h})\);
- pH of dialyzate, concentrate and initial solution;
- volumes of the received concentrate \((V_j)\) and desalinated solution \((V_j)\);
- direct current supplied to the device, I, mA.

After completion of each cycle, the samples from the dialyze and concentrate solutions for determination of chromate-ions content were taken (UV-1800 spectrophotometer, SHIMADZU). In the fixed time points, in the course of the process, the electroconductivity \((\text{S/m})\) of the dialyzate and concentrate solutions was measured (HI 98194, HANNA).

RESULTS END DISCUSSIONS

The process of chrome-contained waters desalination and concentration in the electrodialysis device, which initially was equipped with MK-40 and MA-40 ion-exchange membranes, was studied. The MK-40 and MA-40 membranes are produced on the basis of the KU-2 and EDE-10P ionites, respectively. The initial physicochemical properties of these membranes met the technical requirements TU (Technical Specification 6-06-205-91) for such membranes.

The process of desalination and concentration of the chrome-containing solutions by the ED method, was performed with the solution containing chromate-ions of 50 mg/L in condition of applied voltage, \(U = 250\, \text{V}\). The experiment proved that in the case of the MK-40 and MA-40 membranes, the desalination process fails due to “poisoning” (loss of selectivity) of the MA-40 anion exchange membrane with chromate-ions, due to the presence of partial sorption of ions.

Thus, all further experiments were performed by means of the device equipped with the MK-40L and MA-41L ion-exchange membranes. The above-mentioned membranes were reinforced with lavsan fabric for rising of their stability in the aggressive mediums. Unlike the MA-40 membrane, the MA-41L membrane is produced on the basis of strong-base anionite AB-17. Their compliancy with the technical demands TU (Technical Specification 6-06-205-91) was established.

Due to liability of the anion-exchange membranes to “poisoning”, the stability of MA-41L to chromate-ions was researched and the optimal parameters of the ED process were established.

The research of the stabilization process under the conditions of circulation of chrome-containing solutions in the desalination and concentration chambers of the device without supply of current proved that the superficial layer of the MA-41L membrane sorbed chromate-ions and these ions do not practically diffuse into the membrane in spite of great gradient of concentration.

In the case of supply of electric current concentration of Cr\(^{VI}\) in the desalination chamber first dropped \((C_{\text{initial}} = 50\, \text{mg/L})\), but after achievement of 6–8 mg/L, this process slowed down (Figure 4, curve 1). In the concentration chamber, the change of Cr\(^{VI}\) ions concentration achieved its maximum (Fig. 4, curve 2). This fact proves that at low concentration and corresponding low indices of current in the desalination chamber, electromigration of Cr(VI) ions first equals to, but later – is lower than adsorption flow of the ions.

The process of concentration of chromate-ions in the solution was studied. First, the content of chromate-ions in the concentrate grew unevenly, then – by the equal values (25–30 mg/L). The residual concentration of Cr\(^{VI}\) ions in the desalination chamber was 2–4 mg/L in all the experiments. Such condition of the system may be called quasi-stationary, as under these conditions, the value \(\text{dc/dt} V_d\) approximately equaled to \(\text{dc/dt} V_c\). On the basis of the results, it can be concluded that the transfer of chromate-ions to the anion-exchange membranes makes the key stage of electromembrane process.

The efficiency of using current in the process of electrodialysis desalination and concentration of chrome-containing solutions with the yield calculated in the various experiments was assessed.
Figure 5 shows the curves of change of yield depending on the concentration of chromate-ions in the dialysate. As it can be seen, deep desalination of chrome-containing waters is ineffective and it is reasonable to carry out the process up to 8–10 mg/L residual concentration of chromate-ions.

Aiming to establish the possibility of return not only water, but also concentrate to the technological cycle, the possibility of maximum concentration of chromate-ions in the concentration chamber without considerable slowing of the desalination process down was studied. For this purpose, the demineralization process in the concentration chamber was carried out under the same conditions at the various concentrations of the initial solution.

The analysis of the curves given in Fig. 6 clearly shows slowing of the desalination process down. The obtained result gives the basis to provide return into the technological cycle of high salt-containing electrolyte – 20 g/L chrome anhydride after electrodialysis treatment of the wastewater of the chroming process in the galvanic workshop.

After desalination and concentration of chrome-containing solutions by using the electrolysis method, the physicochemical properties of the MK-4IL and MA-41L membranes were studied, namely, static exchange capacity and specific conductivity of the initial membrane in the form Na\(^+\) and CrO\(_4\)\(^{2-}\) after removal from the device and after their regeneration under the static conditions. The received result pointed to the satisfactory condition of the membranes and possibility of their regeneration in case of working with chrome-containing solutions.

The experiments proved that in the case of electrodialysis treatment of chrome-containing solutions, the process of achievement of the stationary
conditions in the system is slow, which may be explained with partial sorption of the chromate-ions to the MA-41L anionite membrane. It was proven that the kinetic properties of the desalination process of chrome-containing solutions lightly changes after sufficient number of cycles (Figure 5), which means achievement of a quasi-stable state.

On the basis of the obtained results, it may be concluded that the electrodialysis device equipped with the MK-40L and MA-41L membranes may be used locally in the closed system of water supply of chroming.

CONCLUSIONS

The single–step process of chromate-ions removal from chrome-containing solutions and their concentration was studied. It was found that:

• it is reasonable to run the process with the device equipped with the MK-40L and MA-41L membranes instead of the MK-40 and MA-40 membranes, due to “poisoning” of these latter by chromate-ions;
• passing of the chromate-ions through the MA-41L anion exchange membranes is a key stage of the electromembrane process;
• kinetic properties of the desalination process of chrome-containing solutions lightly change after completion of the certain quantity of the cycles, which points to achievement of a quasi-stable state in the system;
• deep desalination of chrome-containing waters is ineffective; it is reasonable to carry out this process up to residual concentration of the chromate-ions in the dialyzate 8-10 mg/L;
• maximum concentration of chromate-ions (~20 g/L) is achieved without considerable reduction of the desalination process rate;
• electrodialysis method allows purification of the chrome-containing waters as well as return of the obtained waters and concentrate into the technological cycle.

REFERENCES

1. Adhoum, N., Monser, L., Bellakhal, N., & Belgaid, J. 2004. Treatment of electroplating wastewater containing Cu**2**+, Zn**2**+ and Cr(VI) by electrocoagulation. Journal of Hazardous Materials, 112(3), 207–213.
2. Alekseeva, S.L., Bolotin, S.N., & Tsyupko, T.G. 2007. Sorption of chromium(VI) on ion-exchange resins and sorbents. Russian Journal of Applied Chemistry, 80(3), 376–378.
3. Alvarado, L., Ramírez, A., & Rodriguez-Torres, I. 2009. Cr(VI) removal by continuous electrodeionization: Study of its basic technologies. Desalination, 249(1), 423–428.
4. Arslan, G., & Pehlivan, E. 2007. Batch removal of chromium(VI) from aqueous solution by Turkish brown coals. Bioresource Technology, 98(15), 2836–2845.
5. Barakat, M. 2011. New trends in removing heavy metals from industrial wastewater. Arabian Journal of Chemistry, 4(4), 361–377.
6. Dalla Costa, Roni F., Klein, Cláudia W., Bernardes, Andrea M., & Zoppas Ferreira, Jane. Evaluation of the electrodialysis process for the treatment of metal finishing wastewater. 2002. Journal of the Brazilian Chemical Society, 13(4), 540-547.
7. Fu, F., & Wang, Q. 2011. Removal of heavy metal ions from wastewaters: A review. Journal of Environmental Management, 92(3), 407–418.
8. Gao, P., Chen, X., Shen, F., & Chen, G. 2005. Removal of chromium(VI) from wastewater by combined electrocoagulation and electroflostation without a filter. Separation and Purification Technology, 43(2), 117–123.
9. Gayathri, R., & Senthil Kumar, P. 2010. Recovery and reuse of hexavalent chromium from aqueous solutions by a hybrid technique of electrodialysis and ion exchange. Brazilian Journal of Chemical Engineering, 27(1), 71–78.
10. Gubari, M., Zwain, H., Al-Zaihat, M., & Alekseeva, N. 2021. Characteristics of the MK-40 and MA-40 Membranes for Industrial Wastewater Treatment – A Review. Ecological Engineering & Environmental Technology, 22(1), 39–50.
11. Gode, F., & Pehlivan, E. Removal of chromium(III) from aqueous solutions using Lewatit S 100: The effect of pH, time, metal concentration and temperature. 2006. Journal of Hazardous Materials, 136(2), 330–337.
12. Gurreri, L., Tamburini, A., Cipollina, A., & Micale, G. 2020. Electrodialysis Applications in Wastewater Treatment for Environmental Protection and Resources Recovery: A Systematic Review on Progress and Perspectives. Membranes, 10(7), 146. https://doi.org/10.3390/membranes10070146
13. Hirpara, P., Nikhil, B., & Murty, D.S. 2011. Bacterial Treatment For Removal of Chromium (VI) Containing Electroplating Waste Waters. Indian Journal of Applied Research, 4(6), 436–438.
14. Judd, S., & Jefferson, B. (2003). Membranes for Industrial Wastewater Recovery and Re-use. Elsevier. Gezondheidszorg.
15. Khan, M., Luque, R., Akhtar, S., Shaheen, A., Mehmood, A., Idress, S., Buzdar, S., & Rehman,
16. Korus, I., & Loska, K. 2009. Removal of Cr(III) and Cr(VI) ions from aqueous solutions by means of polyelectrolyte-enhanced ultrafiltration. Desalination, 247(1–3), 390–395.

17. Kozlowski, C.A., & Walkowiak, W. 2002. Removal of chromium(VI) from aqueous solutions by polymer inclusion membranes. Water Research, 36(19), 4870–4876.

18. Marder, L., Bernardes, A. M., & Zoppas Ferreira, J. 2004. Cadmium electroplating wastewater treatment using a laboratory-scale electrodialysis system. Separation and Purification Technology, 37(3), 247–255.

19. Mangaiyarkarasi, M., Vincent, S., Janarthanan, S., Subba Rao, T., & Tata, B. 2011. Bioreduction of Cr(VI) by alkaliphilic Bacillus subtilis and interaction of the membrane groups. Saudi Journal of Biological Sciences, 18(2), 157–167.

20. Mauritiz, K.A., & Moore, R.B. 2004. State of Understanding of Nafion. Chemical Reviews, 35(50), 4535–4586.

21. Melnikov, S., & Shkirskaya, S. 2019. Transport properties of bilayer and multilayer surface-modified ion-exchange membranes. Journal of Membrane Science, 590, 117272.

22. Mirbagheri, S., & Hosseini, S. 2005. Pilot plant investigation on petrochemical wastewater treatment for the removal of copper and chromium with the objective of reuse. Desalination, 171(1), 85–93.

23. Moura, R.C.A., Bertuol, D.A., Ferreira, C.A., & Amado, F.D.R. 2012. Study of Chromium Removal by the Electrodialysis of Tannery and Metal-Finishing Effluents. International Journal of Chemical Engineering, 2012, 1–7.

24. Nataraj, S., Hosamani, K., & Aminabhavi, T. 2007. Potential application of an electrodialysis pilot plant containing ion-exchange membranes in chromium removal. Desalination, 217(1–3), 181–190.

25. Noubl, A., Akretche, D.E., Crespo, J.G., & Velizarov, S. 2020. Complementary membrane-based processes for recovery and preconcentration of phosphate from industrial wastewater. Separation and Purification Technology, 234, 116123.

26. Peng, C., Meng, H., Song, S., Lu, S., & Lopez-Valdivieso, A. 2005. Elimination of Cr(VI) from Electroplating Wastewater by Electrodialysis Following Chemical Precipitation. Separation Science and Technology, 39(7), 1501–1517.

27. Petrov, S., & Nenov, V. 2004. Removal and recovery of copper from wastewater by a complexation-ultrafiltration process. Desalination, 162, 201–209.

28. Sadyrbaeva, T.Z. 2016. Removal of chromium(VI) from aqueous solutions using a novel hybrid liquid membrane-electrodialysis process. Chemical Engineering and Processing: Process Intensiﬁcation, 99, 183–191.

29. Saf, A., Alpaydın, S., Coskun, A., & Ersoz, M. 2011. Selective transport and removal of Cr(VI) through polymer inclusion membrane containing 5-(4-phenoxypyphenyl)-6H-1,3,4-thiadiazin-2-amino as a carrier. Journal of Membrane Science, 377(1–2), 241–248.

30. San Román, M., Ortiz Gándara, I., Ibáñez, R., & Ortiz, I. 2012. Hybrid membrane process for the recovery of major components (zinc, iron and HCl) from spent pickling effluents. Journal of Membrane Science, 415–416, 616–623.

31. Santiago, A.A., Vargas, J., Fomine, S., Gaviño, R., & Tlenkopatchev, M. A. 2010. Polynorbornene with pentafluorophenyl inside side chain groups: Synthesis and sulfonation. Journal of Polymer Science Part A: Polymer Chemistry, 48(13), 2925–2933.

32. Sarapulova, V., Shkorkina, I., Mareev, S., Pismenskaya, N., Kononenko, N., Larchet, C., Dammak, L., & Nikonenko, V. 2019. Transport Characteristics of Fujiﬁlm Ion-Exchange Membranes as Compared to Homogeneous Membranes AMX and CMX and to Heterogeneous Membranes MK-40 and MA-41. Membranes, 9(7), 84. https://doi.org/10.3390/membranes9070084

33. Sardohan, T., Kir, E., Gulec, A., & Cengeloglu, Y. 2010. Removal of Cr(III) AND cr(vi) through the PLASMA modiﬁed and unmodiﬁed ion-exchange membranes. Separation and Purification Technology, 74(1), 14–20. doi:10.1016/j.seppur.2010.05.001

34. Serdiuk, V.O., Sklabinskvyi, V.I., Bolshania, S.B., Ivchenko, V.D., Qasim, M.N., & Zaytseva, K.O. (2018). Membrane Processes during the Regeneration of Galvanic Solution. Journal of Engineering Sciences, 5(2), F1–F6.

35. Scott, K. 1995. Handbook of industrial membranes. Oxford: Elsevier Advanced Technology.

36. Strathmann, H. 1985. Electrodialysis and its application in the chemical Process Industry. Separation and Purification Methods, 14(1), 41–66.

37. Tongwen, X. 2002. Electrodialysis processes with bipolar membranes (EDBM) in environmental protection – A review. Resources, Conservation and Recycling, 37(1), 1–22.

38. Verma, S.S.K., Khandegar, V., & Saroha, A.K. 2013. Removal of Chromium from Electroplating Industry Effluent Using Electrocoagulation. Journal of Hazardous, Toxic, and Radioactive Waste, 17(2), 146–152.

39. Wang, Z., Liu, G., Fan, Z., Yang, X., Wang, J., & Wang, S. 2007. Experimental study on treatment of electroplating wastewater by nanofiltration. Journal of Membrane Science, 305(1–2), 185–195.

40. Xing, Y., Chen, X., & Wang, D. 2007. Electrically Regenerated Ion Exchange for Removal and Recovery of Cr(VI) from Wastewater. Environmental Science & Technology, 41(4), 1439–1443.