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Synthesis and characterization of polymeric inclusion membrane containing Dibenzo-18-Crown- 6 as carrier of uranium ions

Naima Bayou [a]*, Kh. Boukacem [b], F. Houhoune [a], Sihem Khemaissia [a]

[a]*Draria Nuclear Research Center, BP 43, 16003 Draria, Algiers, Algeria.*
[b]*Houari Boumediene University of Science and Technology, USTHB, BP 32, 16111 El-Alia, Algiers, Algeria.*
* *Corresponding author.* E-mail address: *n-bayou@crnd.dz*

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ABSTRACT

Liquid radioactive waste generated during nuclear operations has a variable chemical and radioactive composition. Uranium is among the most dangerous radionuclide present in this liquid waste due to its chemical toxicity and radioactivity, hence the need for its removal from aqueous solutions. Several techniques have been used for this purpose. Polymer inclusion membranes, also called third-generation membranes, are used for this treatment; they have the advantage of being selective because they incorporate specific extractants into their structure. In this study, cellulose triacetate (CTA)-based polymer inclusion membranes containing 2-nitrophenyl octyl ether (2-NPOE) as a plasticizer and dibenzo-18-crown-6 (DB18C6) as a carrier, in different amounts (0.04, 0.07, and 0.1 g), were synthesized. The physicochemical and structural properties of the synthesized membranes were determined. Characterization results from Fourier transform infrared (FTIR) spectroscopy and scanning electron microscopy (SEM) show that DB18C6 is properly incorporated into the polymer matrix of the membrane. Characteristic bands of the polymer, plasticizer, and carrier are present in the FTIR spectra of the CTA-2NPOE-DB18C6 membrane. This result is confirmed by SEM analysis, which reveals that the polymer pores of the membrane are filled by plasticizer and carrier molecules. The performance of the prepared membranes with respect to uranium was studied by determining the amount of uranium fixed to the membrane. The results showed that 0.07 g of DB18C6 is sufficient for maximum uranium binding (92%) to the membrane, compared to membranes containing 0.04 g and 0.1 g of the DB18C6.

Keywords: Liquid waste; Uranium; membrane; DB18C6.

Graphical abstract

Appearance of the elaborated membranes (a: CTA-NPOE-DB18C6 (0.04 g), b: CTA-NPOE-DB18C6(0.07g) and c: CTA-NPOE-DB18C6(0.1g)

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1. Introduction

The fight against environmental pollution, a topic of current concern, has prompted many public and private organizations to take on financial responsibility for this fight. Research to address this alarming pollution has been conducted worldwide. This scourge has worsened with the rapid development of modern industry, which produces increasing quantities of waste, further damaging the environment. Among this waste are radioactive effluents from nuclear operations, whose chemical composition and radionuclide content vary due to their chemical toxicity and radioactivity [1-3]. Uranium is among the most dangerous radionuclides present in the uranyl effluents. In order to protect the environment and human health, the treatment of uranium waste is imperative. Several techniques have been used for this purpose and among these methods are treatment by chemical precipitation, treatment by solvent extraction, treatment by ion exchange, treatment by adsorption on natural or synthetic materials and finally treatment by membrane processes [4-8].

Membrane processes have been used for the recovery of many metals of strategic and economic interest such as uranium, copper, molybdenum, cadmium, lead and zinc, etc [9-11]. Polymer inclusion membranes so-called membranes of third generation have the advantage of being selective because they incorporate specific extractants in their structure which gives them great stability [12]. A polymer inclusion membrane is a novel type of liquid membrane system in which the carrier/extractant is incorporated into the entangled chains of the base polymer [13, 14]. In the polymer inclusion membranes (PIM), the loosing of the carrier from the base polymer into the aqueous phases is very low and alleviates the stability of the membrane.

Several authors have studied the removal of metals by using polymer inclusion membranes, where Baoying et al have presented the recent advances in the selective transport and recovery of metal ions using polymer inclusion membranes [15]. The polymer inclusion membranes were also used in the separation of Methylene Blue and Rhodamin B by the incorporation of acidic extractant in polymer matrix [16], while the acid-modified cellulose acetate membranes were developed by Aburideh et al [17] for salt water treatment. Other studies were focused in the synthesis and characterization of polymer inclusion membrane containing different extractants [13, 18 and 19]. The DB18C6 was used as carrier in polymeric membrane to the transport of silver (I), copper (II) and gold (III) [20].

The objective of this work is to synthesize cellulose triacetate-based polymer inclusion membranes containing dibenzo-18-crown-6 as a carrier, varying its quantity from 0.04 g to 0.1 g. Another objective is to determine the physicochemical and structural properties of the synthesized membranes using Fourier transform infrared (FTIR) spectroscopy and scanning electron microscopy (SEM). The effectiveness of these membranes against uranium will be studied by fixation tests on dilute solutions. The analysis of the results obtained will allow for the selection of the optimal amount of DB18C6.

2. Materials and Methods

2.1. Reagents

Cellulose triacetate (CTA), chloroform, 2nitrophenyl octyl ether (2NPOE) and dibenzo18 crown ether (DB18C6), used in polymeric inclusion membrane preparation, were of analytical reagent grade purchased from Fluka and Sigma-Aldrich.

The uranium (VI) aqueous solutions were prepared in double- distilled water by using Uranyl nitrate UO2(NO3)2.

2.2. Preparation and characterization of polymer inclusion membranes (PIM)

Three polymer inclusion membranes areprepared as described by Suguirain literature [21-23]and our previous work [13]. The PIM based polymer used in this study is cellulose triacetate (CTA), the plasticizer is nitrophenyl octyl ether (NPOE) and the Dibenzo 18crown 6 (DB18C6) is used as a carrier. In a beaker covered with film, 0.2 g of polymer named cellulose triacetate (CTA) is dissolved in 20 mL of chloroform. After 4 hours of stirring, a quantity of 0.2 mL of plasticizer (2NPOE) is added under stirring. Afterwards, the desired quantity of the carrier is incorporated into the entangled chains of the base polymer. The different quantitiesof DB18C6 used in this study are 0.04,0.07 and 0.1 g. Finally, the obtained mixture of polymer, plasticizer and carrier is placed in a 9.2 cm diameter flat bottom glass petri dish. The chloroform was allowed to evaporate slowly overnight to obtain a polymer film with a smooth looking surface. The obtained film was then carefully peeled out from the dish. The obtained membranes are named: CTA-NPOE-DB18C6 (0.04g), CTA-NPOE-DB18C6 (0.07g) and CTA-NPOE-DB18C6 (0.1g). Thus prepared membranes are characterized by FTIR, recorded ona

Perkin-Elmer (Spectrum One) spectrophotometer. The morphologies of the different membranes elaborated are determined by SEM analysis using a scanning electron microscope (QUATA 650).The three membranes are then used in uranium performance experiments.

2.3. Determination of the fixed uranium in the elaborated membranes

To determine the fixed uranium on the different elaborated membranes: CTA-NPOE-DB18C6 (0.04 g), CTA-NPOE-DB18C6 (0.07 g) and CTA-NPOE-DB18C6 (0.1 g), two experiments are carried out for each membrane elaborated. First an 8 cm2 of elaborated membrane is placed in 50 mL of uranyl solution of 50 mg/L and stirred for 24h, after that the remaining solution is analyzed with Optizen Pop, UV visible spectrophotometer at 652 nm, by using the Arsenazo III method [13]. Secondly, the charged membrane is placed in 200 mL of distilled water and stirred for 24 h to desorb the uranium accumulated on the membrane surface. Fixed uranium is obtained by the difference between the retained uranium and the sorbed uranium values.

3. Results and discussion

3.1. Physical and chemical characterization of the synthesized membranes

In the present study, inclusion polymer membranes based on cellulose triacetate (CTA) containing Dibenzo-18-crown-6 (DB18C6) as carrier were developed. Physicochemical characterization of the elaborated membranes is represented in Table 1 and the appearance of the membranes is shown in figure1. The listed membranes made with varying the amount of the carrier are compared with those of the CTA and CTA-2NPOE reference membrane. Referring to previous works on the synthesis polymeric membrane; it has been shown that the quantities of CTA and the plasticizer influence the mechanical characteristics of the membrane where the low amount of CTA leads to a membrane that sticks to the petri dish walls. However, the high volume of the plasticizer provides membranes that tears easily [13, 23 and 24]. After preliminary membrane preparation tests, a mass of 0.2 g of CTA and a volume of 0.2 mL of plasticizer allows homogeneous membranes to be obtained. The membranes produced are homogeneous and transparent for 0.04 g and 0.07 g of DB18C6. The increasing amount of DB18C6 for 0.1 g makes the membrane opaque and whitish (figure 1) which is may be due to the texture of DB18C6 powder.

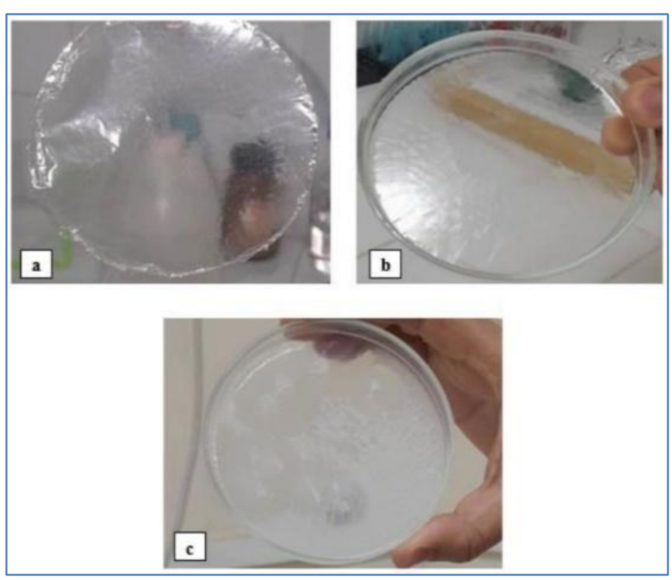

Fig 1. Appearance of the elaborated membranes (a: CTA-NPOE-DB18C6 (0.04 g), b: CTA-NPOE-DB18C6(0.07g) and c: CTA-NPOE-DB18C6(0.1g)

The elaborated membranes have a plasticized character, good mechanical strength, non-rigid and are also resistible. As shown in table 1, the density of the membranes containing the different amount of carrier increases with the addition of the plasticizer and the carrier. In the other hand, the density increases with the increasing quantity of carrier [13, 23].

Table 1. Chemical and physical characteristics of the elaborated membranes

Membrane	DB18C6 (g)	Dencity (mg/cm^2)	Water content (%)	Appearance
CTA	0	3.31	8.33	Transparent, flexible
CTA-2NPOE	0	6.31	4.55	Transparent,flexible
CTA-2NPOE-DB18C6	0.04	8.1	8.18	Transparent, flexible
CTA-2NPOE-DB18C6	0.07	10.69	10.42	Transparent, flexible
CTA-2NPOE-DB18C6	0.1	18.86	13.42	Opaque and whitish, flexible

It is also noted that the increasing amount of the carrier increase the water content, these results are in accordance with those of Oughlis and Paduraru et al [25, 26]. The water content of the elaborated membranes can be classified as follows:

TAC-2NPOE-DB18C6 (0.1 g) > TAC-2NPOE-DB18C6 (0.07 g) >TAC-2NPOE-DB18C6 (0.04 g)

3.2. Structural characterization of the synthesized membranes

3.2.1. FTIR analysis

The values of peaks and corresponding radicals obtained by FTIR analysis of the different membranes synthesized are summarized in Table 2.

Table 2. Peaks values and corresponding functions for the elaborated membranes

Membrane	Peak value (cm^{-1})	Corresponding radicals
CTA	1738.37	C=O
	1367.92	$-CH_3$
	1214.94-1033.18	C-O-C
CTA-2NPOE	2927.48	C-H
	2856.94	$-CH_2$-(NPOE)
	1748.22	C=O
	1608.42	$-NO_2$ (NPOE)
	1524.76	$-NO_2$
	1489.21	$-CH_3$
	1467.37	C-C
	1164	C-O-C
	1042.50	C-O-C
	856.07	C-N
TAC-2NPOE-DB18C6	2960.21	C-H
	2860	$-CH_2$(NPOE)
	1759	C=O (CTA)
	1596	C=C
	1150	C-O-Casym (DB18C6)
	996	C-O-Csym (DB18C6)

The figure 2 represents the FTIR spectra of the different prepared membranes: CTA, CTA-NPOE, CTA-NPOE-DB18C6. We notice that the characteristic peaks of the cellulose triacetate CTA and the plasticizer 2NPOE such as C=O, C-O-C, -NO_2 and C-N groups are found in the polymeric membranes containing theDB18C6 carrier. The FTIR spectra of the CTA-NPOE-DB18C6 show additional bands present in DB18C6 such as symmetric and asymmetric C-O-C bonds at 1150 cm-1 and 996 cm-1. The results confirm that the carrier DB18C6 is incorporated in polymer matrix without chemical bonding between the CTA and DB18C6 [20].

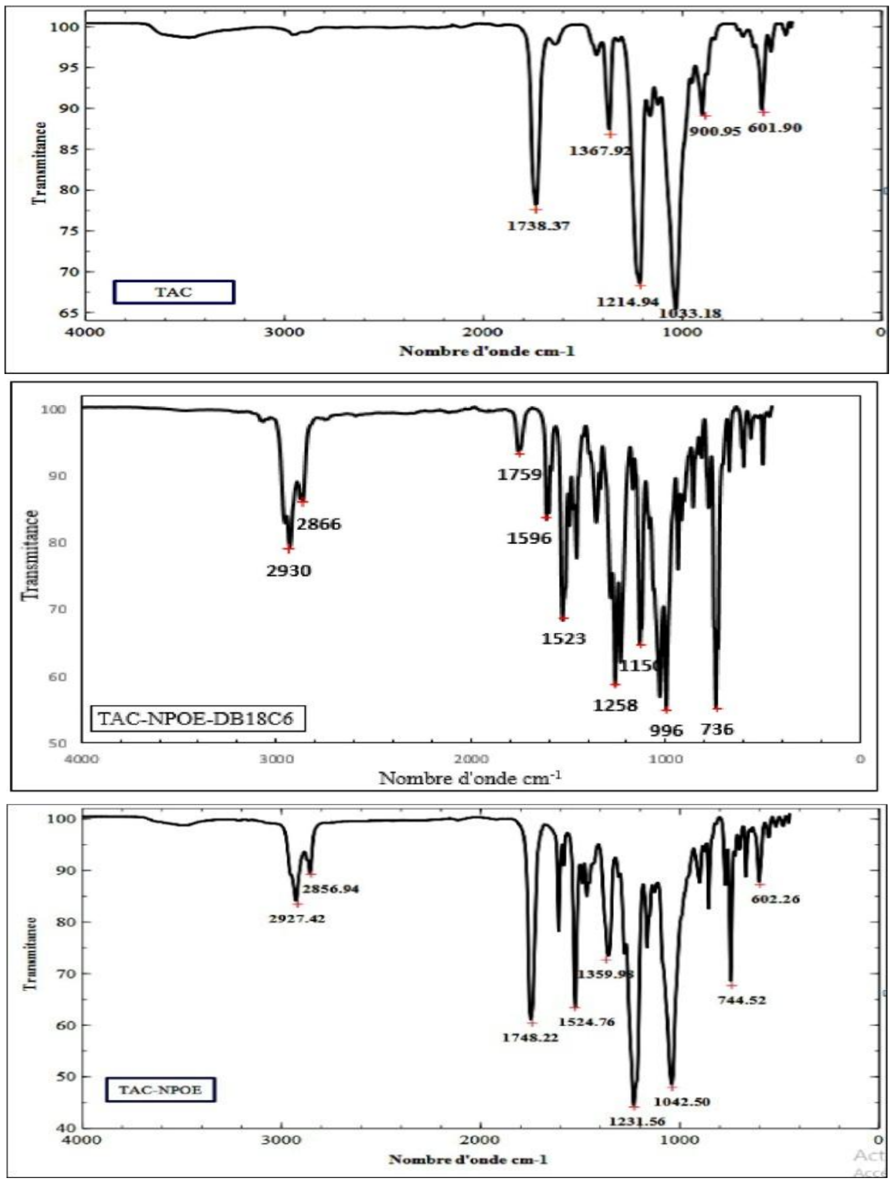

Fig 2. FTIR spectra of polymer inclusion membranes CTA, CTA-NPOE and CTA-NPOE-DB18C6

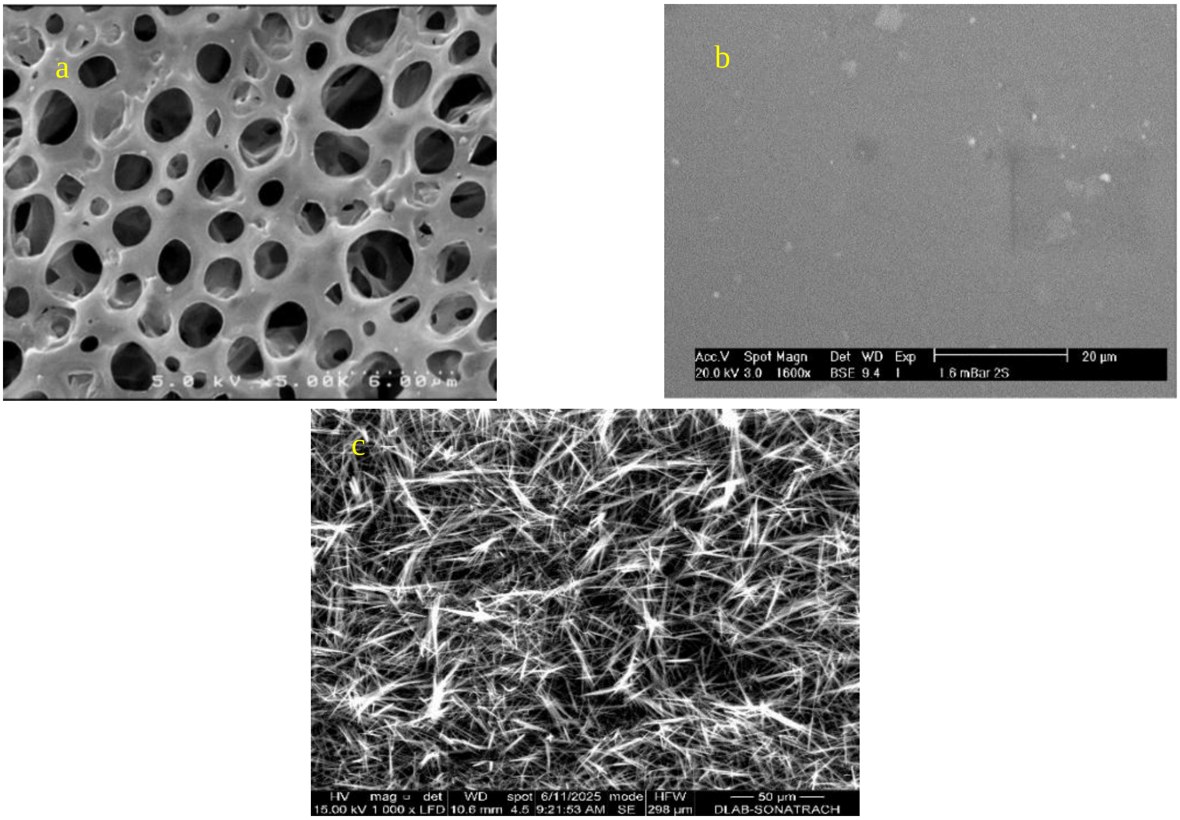

Fig 3. Surface view of CTA (a), CTA-2NPOE (b), CTA-2NPOE-DB18C6(c)

3.3. Application of the elaborated membranes in uranium ions transport

3.3.1. Determination of sorbed and fixed uranium on the elaborated membranes

To study the performance of the elaborated membranes against uranium ions, experiments were conducted as described in section 2.3. The concentrations of sorbed and fixed uranium onto the different membranes are summarized in table 3, where C_0 represents initial uranium concentration and C_{rem} represents remaining uranium concentration.

Table 3. Fixed uranium on the elaborated membranes

Membranes	**Remaining uranium C_{rem}(ppm)**	**C_0– C_{rem} (ppm)**	**Sorbed uranium (ppm)**	**Fixed uranium (ppm)**
CTA	50	0	0	0
CTA-2NPOE	50	0	0	0
CTA-2NPOE-DB18C6 (0,04 g)	17	33	18	15
CTA-2NPOE-DB18C6 (0,07g)	15	35	15	20
CTA-2NPOE-DB18C6 (0,1 g)	20	30	20	10

The results show that the three membranes used in this study fix uranium on the membrane contrary to the reference membranes containing only the polymer and plasticizer. This result confirms that the carrier (DB18C6) can be used for uranium transport. The increasing inserted quantities of the carrier in the polymeric matrix increase the concentration of fixed uranium onto the membrane until 0.07g and then decrease. These results can be explained by the saturation of the membranes by the carrier. It is also due to the solubility limit of DB18C6 in the 2-nitrophenyloctylether (2NPOE) plasticizer. The same resultswere obtained by P.K.Mohapatra, during the study of the effect of the carrier concentration by using polymer inclusion membrane containing crown ethers for selective cesium separation from nuclear waste solution [27].

Complexing sites determination

The determination of the electrolytes number remaining in solution after equilibrium leads to determine the number of molecular sites sorbed and fixed on the membrane [20].The quantities of fixed electrolyte given in table 4 provide access to the number of complexing sites present in the membrane.

Table 4. Fixed uranium electrolytes on the elaborated membranes

Membranes	Sorbed electrolytes10^{-6} (Mole)	Fixed electrolytes10^{-6} (Mole)
CTA-2NPOE-DB18C6 (0,04g)	4.2	2.1
CTA-2NPOE-DB18C6 (0,07g)	2.5	5.8
CTA-2NPOE-DB18C6 (0,1g)	1.6	7.7

knowing that the transporter used form 1:2 complexes with U (VI) ions as describe in the equation 1[28].

$$UO_2^{2+} + 2NO_3^- + 2\,DB18C6_{(org)} \rightarrow UO_2\,(NO3)_2\,2\,DB18C6_{(org)} \quad (1)$$

The table 5 summarized the complexing sites number for the three membranes used in this study. We noticed that the number of complexing sites in the membranes change with the amount of the carrier and the most selective membrane for uranium is that containing 0.07g of DB18C6.

Table 5. Complexing sites number of the different carriers used

Carrier	Molecular SitesNumber10^{18}	Molecular Sites /gram of membrane10^{19}
CTA-2NPOE-DB18C6 (0,04 g)	1,2	1,1
CTA-2NPOE-DB18C6 (0,07 g)	34	3,2
CTA-2NPOE-DB18C6 (0,1 g)	4,6	2,7

4. Conclusion

The results obtained by the physicochemical characterization of the different membranes developed show that the quantities of polymer, plasticizer and carrier are responsible for the quality of the membranes developed and their mechanical characteristics. The results obtained showed that the density increases with the quantity of transporter and that the insertion of transporter reduces the water content comparatively with reference membrane (CTA and CTA-2NPOE). The analysis of the different membranes by scanning electron microscopy revealed that the membrane consisting solely of the CTA polymer is porous throughout the volume (practically 50% porosity) and that the distribution of pores is uniform over the entire surface. Furthermore, the CTA-NPOE-transporter membranes have a dense structure where all pores are filled by NPOE and the transporter. The results of analysis of the membranes by Fourier transform infrared FTIR show that DB18C6 is inserted in polymer matrix without chemical bonding between the base polymer and the carrier. The results obtained from the uranium (VI) transport by using the elaborated membranes show that the three membranes developed are effective for the transport of uranium and the most selective membrane is that containing 0.07g of DB18C6.

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Conflict of Interest

The authors declare that they have no conflict of interest.

References

1. Cheng JG, Leng Y, Gu R, Yang G, Wang Y. Adsorption of uranium (VI) from groundwater by amino-functionalized clay. *J Radioanal Nucl Chem*. 2021;327:1365–73. https://doi.org/10. 1007/ s10967-021-07617-y
2. ElSaid N, Kassem AT. Efficient removal of radioactive waste from solution by two-dimensional activated carbon/nano hydroxyapatite composites. *Membr Water Treat*. 2018;9(5):327–34. https://doi.org/10.12989/mwt.2018.9.5.327.
3. Bayou N, Aït-Amar H, Belkhiri S, Bouhila Z, Houhoune F. Equilibrium, isotherms and kinetic studies of uranium sorption onto $AlPO_4$-5 and SAPO-5 materials. *C R Chim*. 2021;24(2):373–84. https://doi.org/10.5802/crchim.119.
4. Ting X, Qichen L, Jun L, Yong Z, Wenkun Z. Highly enhanced adsorption performance to uranium (VI) by facile synthesized hydroxyapatite aerogel. *J Hazard Mater*. 2022;423:127184. https://doi.org/10.1016/j.jhazmat.2021.127184.
5. Menacer S, Lounis A, Guedioura B, Bayou N. Uranium removal from aqueous solutions by adsorption on Aleppo pine sawdust modified by NaOH and neutron irradiation. *Desalin Water Treat*. 2016;57:16184–95. https://doi.org/10.1080/19443994.2015.1077475.
6. Khebli Z, Djardire R, Boulkrinat A, Bouzerara F. Elaboration of zirconia microfiltration membranes tested with methylene blue filtration. *Desalin Water Treat*. 2022;279:4–7. https://doi.org/ 10. 50 04/dwt.2022.29061.
7. Besharatia N, Alizadeh N, Shariat S. Removal of tetracycline from aqueous solution by Azolla, fig leaves, eggshell and egg membrane modified with magnetite nanoparticle. *Desalin Water Treat*. 2021;225:214–24. https://doi.org/10.5004/dwt.2021.27023.
8. Anirudhan TS, Bringle CD, Rijith S. Removal of uranium(VI) from aqueous solutions and nuclear industry effluents using humic acid-immobilized zirconium-pillared clay. *Desalin Water Treat*. 2009;12(1–3):16–27. https://doi.org/10.5004/dwt.2009.939.
9. Saravanan A, Sankar R, Palanivelu K. Removal of Hg^{2+} ions using tri-n-butylphosphate-based supported liquid membrane from aqueous samples. *Membr Water Treat*. 2021;12(6):293–304. https://doi.org/10.12989/mwt.2021.12.6.293.
10. Nauman A, Nasiha N, Ziarat S, Anwar ul Haq Ali ST. Transportation of molybdenum from model and ore through poly inclusion membrane. *Bull Chem Soc Ethiop*. 2020;34(1):93–104. https://doi.org/10.43 14/bcse.v34i1.9
11. Bensaadi SS, Drai N, Arous O, Berbar Y, Hammache ZE. A study of chromium (VI) ions fixation and transport using polymer inclusion membrane containing D2EHPA as complexing agent. *J Membr Sci Res*. 2022;8(1):531653. https://doi.org/10.22079/jmsr.2021.531653.1470
12. Zioui D, Aoudjit L, Aburideh H, Tigrine Z. Development of acid modified cellulose acetate membranes for salt water treatment. *Cellul Chem Technol*. 2022;56(3–4):353–9. https://doi.org/10.35812/CelluloseChemTechnol.2022.56.31
13. Bayou N, Arous O, Amara M, Kerdjoudj H. Elaboration and characterisation of a plasticized cellulose triacetate membrane containing trioctylphosphine oxide (TOPO): Application to the transport of uranium and molybdenum ions. *C R Chim*. 2010;13:1370–6. https://doi.org/10.1016/j.crci.2010.04.015
14. Nghiem LD, Mornane P, Potter LD, Perera JM, Cattrall RW, Kolev SD. Extraction and transport of metal ions and small organic compounds using polymer inclusion membranes (PIMs). *J Membr Sci*. 2006;281:7–41. http://dx.doi.org/10.1016/j.memsci.2006.03.035
15. Baoying W, Yaoming W, Tongwen X. Recent advances in the selective transport and recovery of metal ions using polymer inclusion membranes. *Adv Mater Technol*. 2023;8(22):2300829. https://doi.org/10.1002/admt.202300829.
16. Aitali S, Kebiche-Senhadji O, Benamor M. Performance of an acidic extractant (D2EHPA) incorporated in IM used for extraction and separation of methylene blue and rhodamine B. *Membr Water Treat*. 2016;7(6):521–37. http://dx.doi.org/10.12989/mwt.2016.7.6.521
17. Aburideh H, Tigrine Z, Aoudjit L, Belgroun Z, Redjimi K, Tassalit D. Development of acid-modified cellulose acetate membranes for salt water treatment. *Cellul Chem Technol*. 2021;55(9–10):1153–61. https://doi.org/10.35812/CelluloseChemTechnol.2021.55.99.
18. Manzak A, Yıldız Y, Tutkun O. Characterization of polymer inclusion membrane containing Aliquat 336 as a carrier. *Membr Water Treat*. 2015;6(2):95–102. https://doi.org/10.12989/mwt.2015.6.2.095
19. Keskin B, Yuksekdag A, Zeytuncu B, Koyuncu I. Development of polymer inclusion membranes for palladium recovery: Effect of base polymer, carriers, and plasticizers on structure and performance. *J Water Process Eng*. 2023;52:103576. https://doi.org/10.1016/j.jwpe.2023.103576
20. Gherrou A, Kerdjoudj H, Molinari R, Seta P, Droli E. Fixed-site plasticized cellulose triacetate membranes containing crown ethers for silver(I), copper(II), and gold(III) ions transport. *J Membr Sci*. 2004;228:149–57. https://doi.org/10.1016/j.memsci.2003.10.003.

21. Sugiura M, Kikkawa M, Urita S. Effect of plasticizer on carrier-mediated transport of zinc ion through cellulose triacetate membranes. *Sep Sci Technol*. 1987;22(11):2263–75.
22. Sugiura M, Kikkawa M, Urita S. Carrier-mediated transport of rare earth ions through cellulose triacetate membranes. *J Membr Sci.* 1989;42(1–2):47–55. https://doi.org/10.1016/ S0376-7388(00)82364-916
23. Aoues A, Merdoud O, Boulakradeche MA, Arous O, Abdessemed D. Preparation and characterization of polymer inclusion membranes based on biodegradable cellulose/Algerian clay for heavy metals removal from wastewater. *Cellul Chem Technol*. 2024;58(7–8):891–9.
24. Van Eygen G, Van der Bruggen B, Buekenhoudt A, Luis A, Lconero P. Efficient membrane-based affinity separations for chemical applications: A review. *Chem Eng Process*. 2021;108613. https://doi.org/10.1016/j.cep.2021.108613
25. Oughlis-Hammache F, Skiba M, Hallouard F, Moulahcene L, Kebiche-Senhadji O, Benamor M, Lahiani-Skiba M. Synthesis and characterization of poly(vinyl alcohol)-poly(β-cyclodextrin) copolymer membranes for aniline extraction. *Membr Water Treat*. 2016;7(3):223–40. https://doi.org/10.12989/mwt.2016.7.3.223
26. Padurar OM, Vasile C, Patachia S, Grigoras C, Opera AM. Membranes based on polyvinyl alcohol/beta-cyclodextrin blends. *Polimery*. 2010;10(6):473–84.
27. Mohapatra PK, Lakshmi DS, Bhattacharyya A, Manchanda VK. Evaluation of polymer inclusion membranes containing crown ethers for selective cesium separation from nuclear waste solution. *J Hazard Mater*. 2009;169:472–9. https://doi.org/10.1016 /j.jharmat.2009.03.124
28. Chaibou Yacouba AR, Laouli Ibrahim S, Sanda Mamane O, Mohamed O, Natatou I. Extraction liquide-liquide de l'uranium et de quelques métaux restrictifs issus des jus uranifères de la République du Niger par l'acide di-2-éthylhexylphosphorique et l'oxyde de trioctylphosphine. *Int J Biol Chem Sci*. 2018;12(5):2424–37. https:// doi.org/10. 4314 /ijbcs .v12i5.39