J Incl Phenom Macrocycl Chem (2011) 71:537–543
DOI 10.1007/s10847-011-9944-3

ORIGINAL ARTICLE

# Calix[4]azacrowns as ionophores for liquid–liquid extraction and facilitated transport of biological supramolecular complexes

**Ioana Varduca Enache · Lucia Mutihac · Amel Ben Othman · Jacques Vicens**

Received: 13 February 2011 / Accepted: 19 February 2011 / Published online: 24 March 2011


**Abstract** The native and methyl ester amino acids have been extracted by calix[4]azacrowns **1** (1,3-[ethylene-bis-aminocarbonylmethoxy)]-*p*-tert-butylcalix[4]arene) and **2** (1,3-[propylene-bis-aminocarbonylmethoxy)]-*p*-tert-butyl-calix[4]arene) from an aqueous phase into a chloroform phase and transported through a chloroform liquid membrane as ion pairs in the presence of picrate or tropaeolin 00 as counter ions aiming their separation. The amino acids under study exhibited good extractability by calix[4]-azacrowns **1** and **2**. Both receptors **1** and **2** showed good extractability towards amino acids under study. The results are discussed in term of correlation of structural properties of amino acids and calix[4]azacrowns involved in experiments. In this respect, the influence of chain length of receptors upon extraction and transport of amino acids, and the nature of anions used as counter ions are evaluated.

**Keywords** Calix[4]azacrowns · Amino acid native and methylesters · Extraction · Membrane transport · Separation

## Introduction

The selective recognition, sensing, and separation of biomolecules by synthetic receptors is a topic of current interest in chemistry with applications in biochemistry, medical diagnostics, drug delivery, as well as in analytical field [1–7]. Recent advances in macrocyclic receptors further extend the range of biomolecules that may be recognition and separation by these receptors. Along with crown ethers, steroids, cyclodextrins, and cucurbit[n]urils, calix[n]arenes belong to the family of synthetic receptors compounds [8–17]. Moreover, the potential of calix[n]arenes and their derivatives to be incorporated onto ion transporting or channelling systems has been pointed out [18, 19].

In recent years, much attention has been focused on the use of calixarenes for chemical and biological applications because of their tunable shape by linker length and cavity size and easy functionalization by specific functions [20, 21]. The control of the conformational properties of these receptors is important for their applications because the complexation behaviour seems to be mainly determined by the conformational mobility of calixarenes. In this respect to improve the binding properties of calixarenes the cavity has been expanded or rigidified by bridges or even caps which leads to calixcrowns. Hence, the calixcrowns have been developed, since Ungaro et al.[22] synthesized for the first time calixcrown, carrying bridging polyethylenoxy moieties on the lower rim which, through variation of calixarene conformation and crown cavity size have shown recognition abilities for metals and also for biomolecules [23, 24]. This family of ligands and their studies has given rise to another family namely calix(aza)crowns which involves molecules combining calix[4]arene elements and oxo-azacrown diamidocrown) units in their framework [25]. Almost all calix[4]azacrowns known to date contain at least some of their aza-atoms as amide units and thus are not simple azacrowns.

The synthesis, recognition, and ion binding properties by means of coordination and stability constants of some

I. V. Enache · L. Mutihac (✉)
Department of Analytical Chemistry, University of Bucharest, 4-12 Regina Elisabeta Blvd., Bucharest 030018, Romania
e-mail: mutihac@astralnet.ro

A. B. Othman · J. Vicens (✉)
IPHC-ULP-ECPM-CNRS, 25, rue Becquerel, 67087 Strasbourg, France
e-mail: vicens@chimie.u-strasbg.fr

calix(aza)crowns compounds, predominantly such derivatives of calix[4]arene has been reported highlighting the complexation abilities of these compounds towards metal ions and mentioning the reduction of the amide units in presently systems to give true polyaza macrocycles in the case of transition metal ions [26, 27]. The quantitative data now available concerning their ability to bind anions and cations indicate that they are an important and useful class of complexants [28, 29]. So far, a few data concerning molecular recognition of calix(aza)crowns towards ammonium ions have been reported.

Amino acids and their derivatives are also bound by calixarenes, particularly aromatic amino acids or basic such as lysine and arginine, and peptides containing these residues [9, 30–32]. The recognition abilities of chiral calix[4]azacrown derivatives towards some α-amino acid methyl esters studied by a UV–Vis titration method have been investigated and the complexation possibly occurs through interaction of the nitrogen atom in the azacrown loop and the quaternary ammonium cation in the α-amino acid methyl esters [33].

In previous works we have reported some analytical applications of functionalized calix[4]arene varyingly substituted by acid or amido functions, glycolic chains and hydroxyl groups towards biological compounds [34, 35]. It was observed that the functionalities, mainly the OH groups, glycolic chains, and amido functions known for their ability to form hydrogen bonds, oxygen-cation interactions and electrostatic interactions may play a role in binding of the amino acid ester through the interactions with the ammonium cation. Our research on this line demonstrated that functionalized calix[4]arenes having additional binding sites enhance the binding ability of the parent calix[4]arenes.

We report herein the solvent extraction of native and methyl esters amino acids with calix[4]azacrowns such as **1** (1,3-[ethylene-bis-aminocarbonylmethoxy)]-*p*-tert-butyl-calix[4]arene) and **2** (1,3-[propylene-bis-aminocarbonyl-methoxy)]-*p*-tert-butyl-calix[4]arene) together with their transport through chloroform liquid membrane in order to achieve their separation.

## Experimental

### Reagents

The following analytical grade amino acids native and methylesters: L-alanine (L-Ala), L-valine (L-Val), L-leucine (L-Leu), L-isoleucine (L-Ile), L-tryptophan (L-Trp), L-phenylalanine (L-Phe), L-tyrosine (L-Tyr), L-tryptophane methylester hydrochloride (L-TrpOMe), L-phenylalanine methylester hydrochloride (L-PheOMe), L-tyrosine methylester hydrochloride (L-TyrOMe), L-valine methylester hydrochloride (L-ValOMe), L-leucine methylester hydrochloride (L-LeuOMe), L-serine methylester hydrochloride (L-SerOMe), L-threonine methylester hydrochloride (L-ThrOMe), and L-cysteine methylester hydrochloride (L-CysOMe) were purchased from Fluka (purity > 99.5%) and were employed without further purification (Chart 1). [4-(4′-Anilinophenylazo) benzenesulfonic acid] (tropaeolin 00) and picric acid as counterions were supplied by Fluka at the analytical grade. Chloroform (dielectric constant $\varepsilon_r = 4.81$) [36] was distilled before use. Distilled (Millipore) water was used throughout the experiments. Calix(aza)crowns (**1**) and (**2**) were prepared as described in a previous paper [24, 25] (Chart 2).

### Liquid–liquid extraction of amino acids by calix[4]azacrowns (**1**) and (**2**)

The extractions of amino acids from water into chloroform were performed according to Pedersen's procedure [37]. Equal volumes (5 mL) of $5.0 \times 10^{-4}$ M to $1.0 \times 10^{-3}$ M of amino acid methylester or native amino acid and $3.0 \times 10^{-5}$ M tropaeolin 00 or $8.0 \times 10^{-5}$ M picric acid at pH = 5.5 in buffer aqueous phases (by using MES/

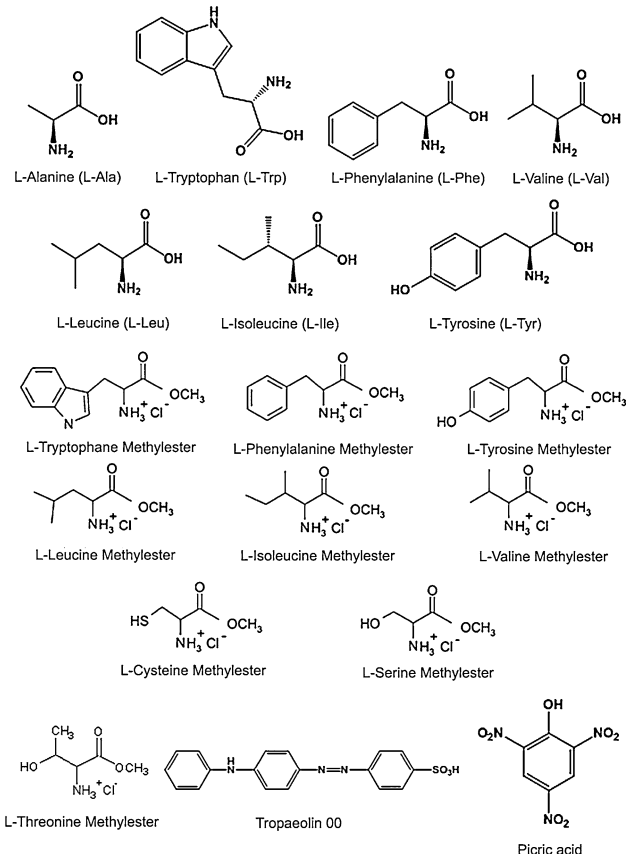


**Chart 1** Chemical structures of amino acids and counterions used throughout the experiments

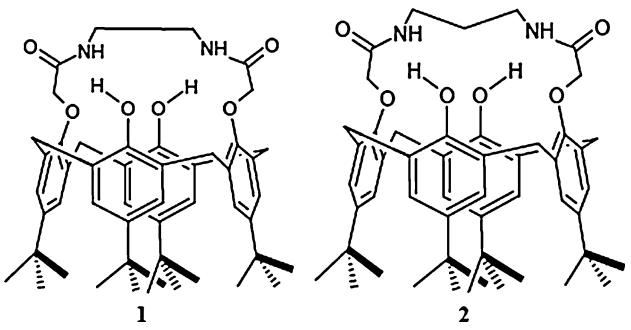


**Chart 2** Chemical structures of calix[4]azacrowns (**1**) and (**2**)

NaOH buffer system) were mixed with chloroform solution (5 mL) of calix[4]azacrowns (**1**) and (**2**), $1.25 \times 10^{-4}$–$5.0 \times 10^{-4}$ M in a stopper test tube and shaken for 30 min at 298.15 K to attend equilibrium. The extractability was calculated as $E\,[\%] = \frac{(A_0 - A)}{A_0} \times 100$, where $A_0$ and $A$ are the absorbances of the aqueous phases before and after the extraction with calixarenes, respectively ($\lambda = 440$ nm in the case of tropaeolin 00 ion, and $\lambda = 345$ nm in the case of picrate ion). The absorbance was determined by spectrophotometric measurements carried out by means of an UV–Vis Spectrometer JASCO V-530. Each experiment was repeated five times.

The pH was measured by a digital MV-870 Pracitronic pH-meter with glass electrode and saturated calomel electrode. The pH of the aqueous solutions was adjusted by the hydrochloric acid. Chloroform and water were saturated with each other to prevent volume change during extraction.

### Liquid membrane transport

The transport experiments were carried out by using a U-shaped glass tube. The source phase contains 10 mL of amino acid buffer aqueous solution (the concentrations ranged between $2.5 \times 10^{-4}$ and $1.0 \times 10^{-3}$ M depending of the amino acid), and $3.0 \times 10^{-5}$ M tropaeolin 00 or $8.0 \times 10^{-5}$ M picrate anion as counterion at pH = 5.5. The receiving phase contains 10 mL of aqueous solution (pH = 1.5). The membrane phase, 25 mL of calix[4]-azacrowns (**1** or **2**) of $5.0 \times 10^{-4}$ M in chloroform was introduced in the tube. Transport experiments were carried out by stirring the aqueous and organic phases at 200 rpm at room temperature for 24 h. The concentration of amino acids in both the aqueous phases (source and receiving phase) was determined by UV–Vis measurements with an UV–Vis Spectrometer JASCO V-530. Each experiment was repeated three times and reproducibility was ±10%. Blank experiments were performed for reference in the absence of carrier. The pH was measured by a digital MV-870 Pracitronic pH-meter with glass electrode and saturated calomel electrode.

## Results and discussion

### Extraction and transport of amino acids as ion pairs in the presence of picrate as counter ion

The yields value of extraction efficiency of some native and methylesters amino acids obtained by using calix[4]azacrown (**1**) and (**2**) as extractants are presented in Fig. 1. The high extractability of both extractants towards amino acids as ion pairs in the presence of picrate anion from aqueous phase into chloroform phase are observed starting from 82% (L-TrpOMe) up to 99% (L-SerOMe) by using receptor **1** and from 89% (L-Ala) up to 98% (L-PheOMe) by receptor **2**. The order of the extractabilities of amino acids with receptor **1** was found to be as follows: L-SerOMe (98%) ≈ L-ValOMe (98%) > L-Ala (91%) > L-LeuOMe (88%) > L-PheOMe (84%) > L-TrpOMe (82), and with receptor **2** as follows: L-PheOMe (99%) > L-LeuOMe (97%) > L-TrpOMe (82) > L-Ala (89%).

The extractability of receptors **1** and **2** towards some amino acids could depend on parameters such as the nature of the guest (lipophilicity or hydrophobicity and its structure), the structure of the receptor or the type of the counter ion together with the interfacial thermodynamic equilibria.

At first glance the extraction yields obtained by using calix[4]azacrown (**2**) are larger than those obtained by calix[4]azacrown (**1**) for the same amino acids with one order of magnitude. Obviously, the structure of the receptor drives the results. The calix[4]azacrown (**2**) has an additional methylene group in the bridging chain. It has been observed that the incorporation of one methylene group on the bridge chain of the ligand slightly influences calixarene conformation [23]. Contrarily to the low extraction results obtained for the extraction of alkaline earth and transition metal picrates from water to dichloromethane with the same receptors **1** and **2**, the values of extraction yields of amino acids are higher [21].

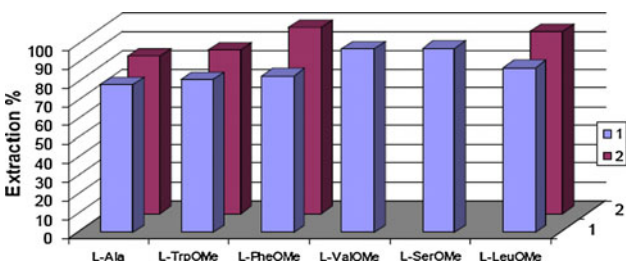


**Fig. 1** Extraction % of amino acids from aqueous phase into chloroform phase by calix[4]azacrown (**1**) and (**2**) in the presence of picrate anion

Another important factor on extraction equilibrium is the nature of the amino acid, more particularly their hydrophobicity. As one can see from Fig. 2 there is no relationship between the extractability of amino acids by calix[4]azacrowns (**1**) and (**2**) carried out under experimental conditions and their hydrophobicity represented by log P [39].

Details of the extracted amino acid complexes composition in the organic phase is obtained by slope analysis of log $D_{\text{amino acid}} - \log c_{L(org)}$ diagram. In this respect, in Fig. 3 are presented the relationship between log D and $-\log c_{\text{calix 1(org)}}$ for the extraction of L-Ala as ion pair in the presence of picrate anion. A linear plot with the slope 1 was obtained for L-Ala, highlighting that the ligand form 1:1 complex with L-Ala under the chosen conditions. The value of extraction constant (log $K_{ex}$) for L-Ala is $\log K_{ex} = 6.71 \pm 0.20$.

The experimental data of the amino acids transport as ion pairs in the presence of picrate ion through chloroform liquid membrane using calix[4]azacrown (**1**) are given in Fig. 4. As in the extraction experiments, receptor **1** exhibited transport ability towards amino acids but with the lower values of transport yields compared with the extraction yields. It was realized an active transport from aqueous source phase into aqueous receiving phase under pH gradient. The sequence of decreasing transport yields of amino acids was the following: L-Ala (43%) > L-SerOMe (42%) > L-ValOMe (33%) ≈ L-TrpOMe (33%) > L-PheOMe (24%) > L-LeuOMe (12%), with the yields varying between 12% for L-LeuOMe and 43% for L-Ala respectively.

As in extraction experiments, calix[4]azacrown (**1**) provided transport ability towards L-SerOMe and L-ValOMe but with lower values of transport yields.

## Extraction and transport of amino acids as ion pairs in the presence of tropaeolin 00 as counter ion

Liquid–liquid extraction experiments performed using calix[4]azacrown (**1**) as extractant in the presence of tropaeolin 00 as counterion show the following sequence of

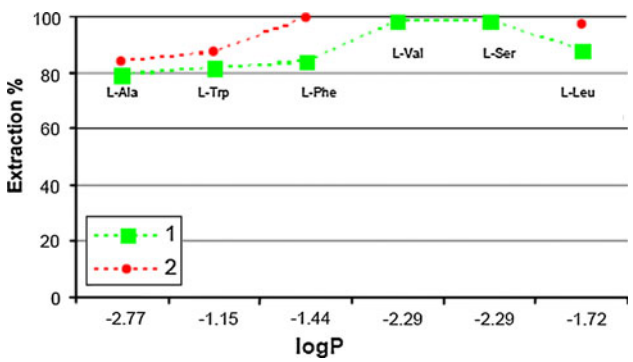


**Fig. 2** Relationship between the extractability of amino acids by calix[4]azacrown (**1**) and (**2**) in the presence of picrate anion as counter ion and their hydrophobicity [38]

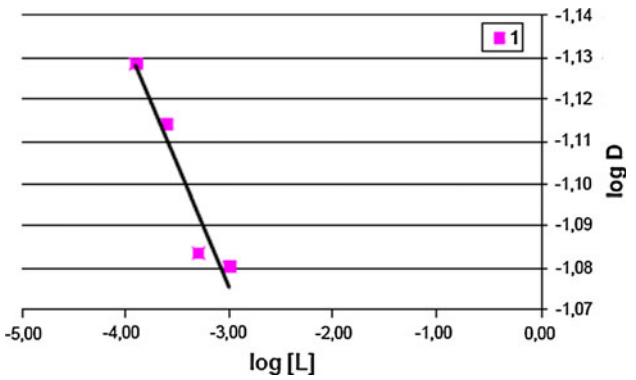


**Fig. 3** Log D versus log[L] for the extraction of L-alanine % with calix[4]azacrown (**1**)

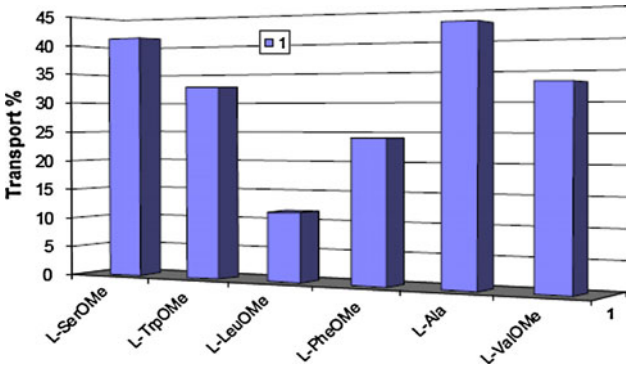


**Fig. 4** Transport yields (%) of amino acids through chloroform liquid membrane by calix[4]azacrown (**1**) as carrier in the presence of picrate as counter ion

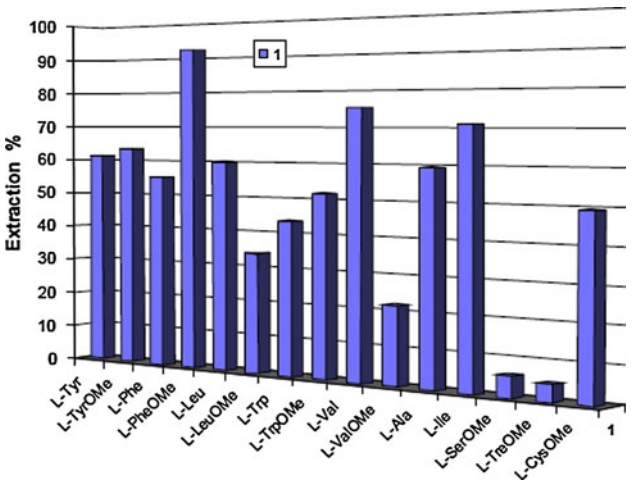


**Fig. 5** Extraction % of amino acids from aqueous phase into chloroform phase by calix[4]azacrown (**1**) in the presence of tropaeolin 00 as counter ion

amino acid methylesters extractability: L-PheOMe (92%) > L-TyrOMe (63%) > L-TrpOMe (52%) > L-CysOMe (49%) > L-LeuOMe (34%) > L-ValOMe (22%) > L-SerOMe (6%) > L-ThrOMe (5%). The extractability yields

vary between 5% (L-ThrOMe) and 92% (L-PheOMe) (Fig. 6).

In the case of native amino acids, the yields of extractability is ranging from 44% (L-Trp) to 75% (L-Val) in the following sequence: L-Val (75%) > L-Ile (71%) > L-Tyr (61%) > L-Leu (60%) > L-Ala (59%) > L-Phe (56%) > L-Trp (44%) (Fig. 5).

As in the case of calix[4]azacrown (**1**), the calix[4]azacrown (**2**) showed high extraction abilities towards amino acid native and methylesters in according with the structure of amino acid. From the data displayed in Fig. 6, one can observed that calix[4]azacrown (**2**) performed higher values of extractabilities towards native and methylester amino acids than calix[4]azacrown (**1**) (Fig. 5) under our experimental conditions. In this respect, the extractability of amino acids methylesters by using calix[4]azacrown (**2**) decreases in the following sequence: L-PheOMe (99%) > L-TyrOMe (83%) > L-CysOMe (49%) > L-LeuOMe (45%) > L-TrpOMe (40%) > L-ValOMe (37%) > L-ThrOMe (32%) > L-SerOMe (10%) and for the native amino acids is the following sequence: L-Ile (98%) > L-Val (96%) > L-Leu (92%) > L-Phe (87%) > L-Tyr (85%) > L-Ala (71%) > L-Trp (62%).

Like in the case of extractability of amino acids in the presence of picrate anion as counter ion, as one can see from Fig. 7 there is no relationship between the extractability of amino acids in the presence of tropaeolin 00 by calix[4]azacrown (**1**) and (**2**) and their hydrophobicity represented by log P [38].

In Fig. 8 it is presented the relationship between log D and $-\log c_{\text{calix 1(org)}}$ for the extraction of L-PheOMe as ion pair in the presence of tropaeolin 00 ion. A linear plot with the slope 1 was obtained for L-PheOMe, highlighting that the calix[4]azacrown (**1**) forms 1:1 complex with L-PheOMe under the chosen conditions. The value of extraction constant (log $K_{ex}$) for L-PheOMe is log $K_{ex} = 6.05 \pm 0.30$.

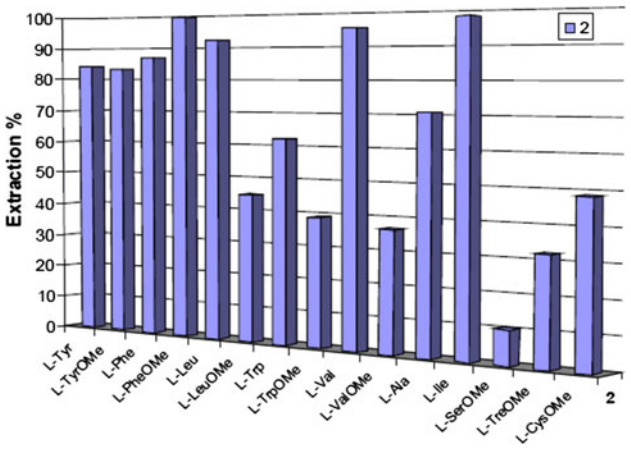


**Fig. 6** Extraction % of amino acids from aqueous phase into chloroform phase by calix[4]azacrown (**2**) in the presence of tropaeolin 00 as counter ion

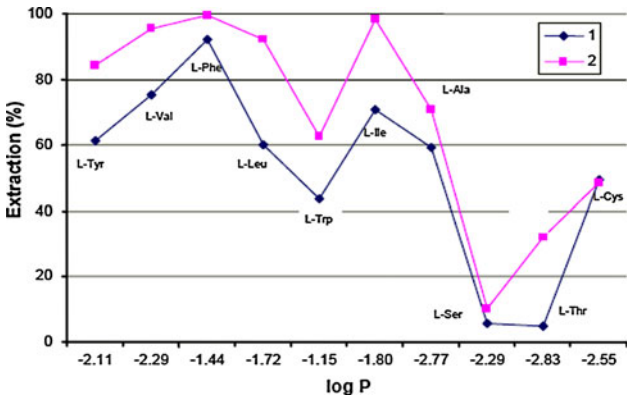


**Fig. 7** Relationship between the extractability of amino acids by calix[4]azacrowns (**1**) and (**2**) in the presence of tropaeolin 00 as counter ion and their hydrophobicity [38]

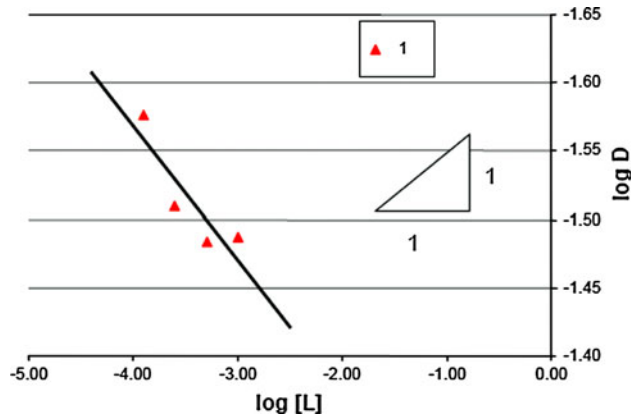


**Fig. 8** Log D versus log[L] for the extraction of L-phenylalanine methylester with calix[4]azacrown (**1**)

## The extraction of amino acids in presence of picrate and tropaeolin 00

The influence of the nature of the anion on extraction is presented in Table 1. It is well-known that the ion to be

**Table 1** Extraction % of some amino acids by calix[4]azacrown (**1**) in the presence of tropaeolin 00 and picrate as counter ion

| Amino acids | Tropaeolin 00% | Picrate % |
|---|---|---|
| L-PheOMe | 92 | 84 |
| L-Ala | 59 | 91 |
| L-TrpOMe | 52 | 82 |
| L-LeuOMe | 34 | 88 |
| L-ValOMe | 22 | 98 |
| L-SerOMe | 6 | 98 |

transferred into the organic phase, must be dehydrated in aqueous phase, otherwise the extraction is made difficult to perform. Because of its higher hydrophobicity the picrate anion is less hydrated than tropaeolin 00. And indeed, except for L-PheOMe, the extraction of some amino acids decreased in the presence of tropaeolin 00 as counterion

## Conclusion

The extraction and transport abilities of calix[4]azacrowns (**1**) and (**2**) were investigated. The results suggested that both calix[4]azacrowns are efficient extractants and carriers of some amino acid native and methylesters as well as exhibiting their separation. From the experimental results it was demonstrated that the extraction and transport through membrane are affected by the structure of calixarenes, the structure of amino acids, and the nature of anion used as counter ion. Thus, the calix[4]azacrown (**2**) is better extractant compared with calix[4]azacrown (**1**) for the amino acids under study and the extraction process was found to be of high extraction values. Concerning the correlation between extractability of the amino acids complexes with calix[4]arenic receptors and their hydrophobicity there is no experimental evidence. Further studies are in progress.

## References


1. Lehn, J.-M.: Supramolecular Chemistry: Concepts and Perspective. Wiley-VCH, Weinheim (1995)
2. Gutsche, C.D.: Calixarenes Revisited. The Royal Society of Chemistry, Cambridge (1998)
3. Vicens, J., Böhmer, V.: Calixarenes: A Versatile Class of Macrocyclic Compounds. Kluwer Academic Publishers, Dordrecht (1991)
4. Mutihac, L., Lee, J.H., Kim, J.S., Vicens, J.: Recognition of amino acids by functionalized calixarenes. Chem. Soc. Rev. (2011). doi:10.1039/c0cs00005a (on-line)
5. Vicens, J., Harrowfield, J. (eds.): Calixarene in the Nanoworld. Springer, Dordrecht (2007)
6. Buschmann, H.-J., Mutihac, L.: Complexation, liquid-liquid extraction, and transport through a liquid membrane of protonated peptides using crown ethers. Anal. Chim. Acta **466**, 101–108 (2002)
7. Dondoni, A., Marra, A.: Calixarene and calixresorcarene glycosides: their synthesis and biological applications. Chem. Rev. **110**, 4949–4977 (2010)
8. Mokhtari, B., Pourabdollah, K., Dalali, N.: Analytical applications of calixarenes from 2005 up-to-date. J. Incl. Phenom. Macrocycl. Chem. **69**, 1–55 (2011)
9. Coleman, A.W., Perret, F., Mousa, A., Dupin, M., Guo, Y., Perron, H.: Calix[n]arenes as protein sensors. Top. Curr. Chem. **277**, 31–88 (2007)
10. Buschmann, H.-J., Mutihac, R.-C., Schollmeyer, E.: Complex formation of crown ethers and cryptands with alkali metal and ammonium ions in chloroform. J. Solution Chem. **38**, 209–217 (2009)
11. Böhmer, V.: Calixarenes, macrocycles with (almost) unlimited possibilities. Angew. Chem. Int. Ed. Engl. **34**, 713–745 (1995)
12. Mutihac, R., Cicuttin, A., Mutihac, R.-C.: Entropic approach to information coding in DNA molecules. Mat. Sci. Eng. **18**, 51–60 (2001)
13. Chen, C.-F.: Novel triptycene-derived hosts: synthesis and their applications in supramolecular chemistry. Chem. Commun. **47**, 1674–1688 (2011)
14. Buschmann, H.-J., Mutihac, L., Mutihac, R.-C., Schollmeyer, E.: Complexation behavior of cucurbit[6]uril with short polipeptides. Thermochim. Acta **430**, 79–82 (2005)
15. Sansone, F., Baldini, L., Casnati, A., Ungaro, R.: Calixarenes: from biomimetic receptors to multivalent ligands for biomolecular recognition. New J. Chem. **34**, 2715–2728 (2010)
16. Mutihac, L.: Functionalized calix[n]arenes as membrane transporters for biological compounds. A minireview. Curr. Drug. Discov. Technol. **5**, 98–104 (2008)
17. Buschmann, H.-J., Schollmeyer, E., Wenz, G., Mutihac, L.: Solvent influence upon complex formation between crown ethers and unprotonated amines. Thermochim. Acta **261**, 1–5 (1995)
18. Fyles, T.M.: Synthetic ion channels in bilayer membrane. Chem. Soc. Rev. **36**, 335–347 (2007)
19. Iqbal, K.S.J., Cragg, P.J.: Transmembrane ion transport by calixarenes and their derivatives. Dalton Trans. **1**, 26–32 (2007)
20. Cao, D., Kou, Y., Liang, J., Chen, Z., Wang, L., Meier, H.: A facile and efficient preparation of pillararenes and a pillarquinone. Angew. Chem. Int. Ed. **48**, 9721–9723 (2009)
21. Kim, J.S., Quang, D.T.: Calixarene-derived fuorescent probes. Chem. Rev. **107**, 3780–3799 (2007)
22. Alfieri C, Dradi E, Pochini A, Ungaro R, Andreetti GD (1983) Synthesis, and X-ray crystal and molecular structure of a novel macro-bicyclic ligand:crowned *p*-t-butyl-calix[4]arene. J Chem Soc Chem Commun 1075–1077)
23. Casnati, A., Pochini, A., Ungaro, R., Ugozzoli, F., Arnaud-New, F., Fanni, S., Schwing-Weill, M.-J., Egberlink, R.J.M., de Jong, F., Reinhoudt, D.N.: Synthesis, complexation, and membrane transport studies of 1,3-alternate calix[4]arene-crown-6 conformers: a new class of cesium selective. J. Am. Chem. Soc. **117**, 2767–2777 (1995)
24. Asfari, Z., Wenger, S., Vicens, J.: Calixcrowns and related molecules. Pure Appl. Chem. **67**, 1037–1043 (1995)
25. Ostaszewski, R., Stevens, T.W., Verboom, W., Reinhoudt, D.N., Kaspersen, F.M.: Calix(aza-)-crowns as potential ionophores for divalent and trivalent cations. Recl. Trav. Chim. Pays-Bas **110**, 294–298 (1991)
26. Oueslati, I.: Calix(aza)crowns: synthesis, recognition, and coordination. A mini review. Tetrahedron **63**, 10840–10851 (2007)
27. Abidi, R., Oueslati, I., Amri, H., Thuery, P., Nierlich, M., Asfari, Z., Vicens, J.: Synthesis, structure and complexing properties of new calix[4](aza)crowns. Tetrahedron Lett. **42**, 1685–1689 (2001)
28. Oueslati, I., Thuéry, P., Shkurenko, O., Suwinska, K., Harrowfield, J., Abidi, R., Vicens, J.: Calix[4]azacrowns: self-assembly and effect of chain length and O-alkylation on their metal ion-binding properties. Tetrahedron **63**, 62–70 (2007)
29. Kim, J.S., Son, O.J., Ko, J.W., Cho, M.H., Yu, I.Y., Vicens, J.: Synthesis and metal ion complexation studies of proton-ionizable calix[4]azacrown ethers in the 1,3-alternate conformation. J. Org. Chem. **65**, 2386–2392 (2000)
30. Danylyuk, O., Suwinska, K.: Solid-state interactions of calixarenes with biorelevant molecules. Chem. Commun. 5799–5813 (2009)
31. Mutihac, L., Buschmann, H.-J., Tudorescu, A., Mutihac, R.: Some aspect of extractability and trasport of amino acid esters by calixarenes. J. Incl. Phenom. Macrocycl. Chem. **47**, 123–128 (2003)

32. Douteau-Guevel, N., Perret, F., Coleman, A.W., Morel, J.-P., Morel-Desrosiers, N.: Binding of dipeptides and tripeptides containing lysine or arginine by p-sulfonatocalixarenes in water: NMR and microcalorimetric studies. J. Chem. Soc. Perkin Trans. **2**, 524–532 (2002)
33. Demirtas, H.N., Bozkurt, S., Durmaz, M., Yilmaz, M., Sirit, A.: Chiral calix[4]azacrowns for enantiomeric recognition of amino acid derivatives. Tetrahedron **65**, 3014–3018 (2009)
34. Kim, L., Hamdi, A., Stancu, A.D., Souane, R., Mutihac, L., Vicens, J.: Selective membrane transport of aminoa cids by functionalized calix[4]arenes. J. Incl. Phenom. Macrocycl. Chem. **66**, 55–59 (2010)
35. Hamdi, A., Souane, R., Kim, L., Mutihac, L., Vicens, J.: Extraction behaviour of amino acid esters by functionalised calix[4]arenes. J. Incl. Phenom. Macrocycl. Chem. **64**, 95–100 (2009)
36. Marcus, Y.: Ion Solvation. Wiley, Chichester (1985)
37. Pedersen, C.J.: Ionic complexes of macrocyclic polyethers. J. Fed. Proc. Fed. Am. Soc. Exp. Biol. **27**, 1305–1309 (1968)
38. Tayar, N.El., Tsai, R.S., Carrupt, P.A., Testa, B.: Octan-1-ol-water partition coefficients of zwitterionic a-amino acids. Determination by centrifugal partition chromatography and factorization into steric/hydrophobic and polar components. J. Chem. Soc., Perkin Trans. **2**, 79–84 (1992)