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## Influence of Nonionic Surfactants as Competitive Carriers in Bulk Liquid Membrane Transport of Metal Cations Using Macrocyclic Ligands

Mersiha Suljkanović <sup>1\*</sup>, Edita Nurković <sup>2</sup>, Jasmin Suljagić <sup>2</sup>

<sup>1</sup> Faculty of Natural Sciences and Mathematics, Univerzitetska 4, 75000 Tuzla  
University of Tuzla, Bosnia and Herzegovina

<sup>2</sup> Faculty of Technology, University of Tuzla, Univerzitetska 8, 75000 Tuzla  
University of Tuzla, Bosnia and Herzegovina

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**Abstract:** Surface active agents (surfactants) find wide application in different analytical procedures due to their amphiphilic properties and possibility of micellar aggregation. In previously published papers, interactions between different metal ions and surfactants were observed, mostly through different membrane transport techniques (emulsion liquid membranes, supported liquid membranes, bulk liquid membranes). However, standard explanation of those interactions, based on host-guest mechanism was expanded with the mechanism of micellar solubilization of metal ions or their complexes within the surfactant aggregates (micelles). In this paper, interactions of nonionic surfactants with metal ions and macrocyclic ligands within the nonpolar liquid organic membranes were investigated. Bulk liquid membrane systems were prepared on the basis of two aqueous phases: source phase (contained cations and counter ions), receiving phase (contained stripping agents) and nonaqueous (nonpolar organic) phase (contained "carriers" for cations). Nonionic surfactants were tested as possible carriers for cations, compared to macrocyclic ligands.

Experiments were performed using the homemade transport cell. Metal ions concentration in aqueous phases was monitored by flame atomic absorption spectrophotometry, after 3 hours of membrane transport. Macrocyclic ligands: 18-crown-6, dibenzo-18-crown-6, dicyclohexano-18-crown-6 and benzo-18-crown-6 dissolved in organic solvents (dichloromethane, 1,2-dichloroethane and chloroform) were used as carriers for cations. Nonionic surfactants: TX-100, Brij 35, Brij 58 and Brij 78 were investigated as possible competitive carriers within the membranes. Experiments were based on the transport of Pb(II) and Cd(II) ions. The effect of surfactant application results in reduced cation transport, compared to macrocyclic ligand carriers, probably caused by additional cation-surfactant interactions within the membrane.

**Keywords:** nonionic surfactants, Pb(II), Cd(II), macrocyclic ligands, bulk liquid membrane

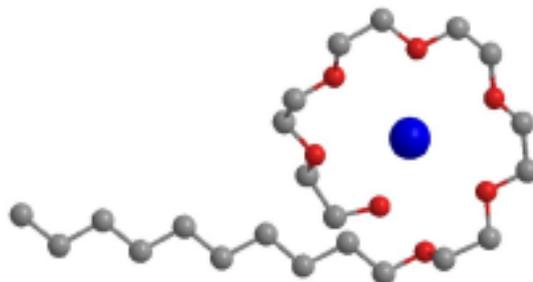
## INTRODUCTION

Among the numerous techniques for efficient removal of metal cations from natural resources, based on an investigation of metal ion complexation with suitable ligands, transport through the liquid organic membranes (bulk liquid membranes, BLM) has lately attracted particular attention of researchers.<sup>1,2</sup> Since the interactions between metal cations and ligands ("host-guest" interactions) depend on many factors, the resulting stability of the formed complexes can be increased by varying of experimental conditions during transport experiments, i.e. during complex formation in an organic solvent as a membrane. The most important factor influencing the complex formation is the compatibility between "the host" (ligand molecule) and "the guest" (metal ion). Also, the temperature and other factors such as type of solvent, type of counter ion, presence of coexisting species, etc., have a certain influence on the complex stability. Polyether ligands are among the most suitable host molecules for many metal ions due to presence of oxygen atoms in their structure (as electron donors). Crown ethers have a specific macrocyclic structure which consists of the polyether chain forming "the crown" with a hydrophilic cavity and a hydrophobic surface. The macrocyclic structure of these ligands provides high stability of formed complexes with metal ions due to the "macrocyclic effect".<sup>3</sup>

Modeling of structural characteristics of ligands (the ring size, the type and number of donor atoms, different substituents, etc.) can increase or decrease their affinity and selectivity toward certain metal ions. Also, the amphiphilicity of their molecules provides the ability of their implementation in polar and nonpolar solvents. Furthermore, there are also types of nonionic surfactants whose molecules consist of polyether chain as a polar part (hydrophilic "head") and hydrocarbon as a nonpolar part (hydrophobic "tail"). Their amphiphilicity provides micellization, e.g. formation of their aggregates in both polar and nonpolar solvents ("normal" and "reverse" micelles). Organisation and aggregation of monomeric surfactant molecules into polymeric micellar structures begins at specific concentration value, "critical micellar concentration" (CMC). Below the CMC, only monomeric molecules exist in solution, above the CMC, added surfactant molecules incorporate in already formed micellar structures.<sup>4</sup>

It can be assumed that these surfactant molecules use oxygen atoms in their polyether chains as electron-donors for metal cations (electron acceptors).<sup>5</sup> Stevens *et al.*<sup>6</sup> explained interactions based on the principle of molecular recognition (the "host-guest" relations), resulting in the formation of complex compounds.

However, in most cases, solubilization of cations by their incorporation in micellar structures is the main explanation for cation-surfactant interactions. Edbey *et al.*<sup>7</sup> investigated interactions between Cd(II) ions and nonionic surfactant HEGMDE (hexaethylene glycole monodecyl ether), using the EMS method (Electrospray Mass Spectrometry). They proposed the possible structure (**Figure 1.**) which implies that a HEGMDE molecule is similar to the crown ether and provides interactions between six oxygen atoms in the polyether chain and Cd(II) ions which results in coiled conformation.<sup>7</sup>



**Figure 1:** Proposed structure of the compound that resulted from interaction between Cd(II) ions and HEGMDE molecule<sup>7</sup>

Characteristics of surfactants: structure of their molecules, values of hydrophilic-lipophilic balance (HLB) and critical micellar concentration (CMC) are important for cation-surfactant interactions. **Table 1.** represents some characteristics of nonionic surfactants used in the experimental part of this paper. There are two groups of used surfactants: polyoxyethylene octylphenyl ethers (Triton X-100) with polyoxyethylene structure of lipophilic part of their molecules; others are polyethoxylated alcohols (Brij 35, Brij 58 and Brij 78).

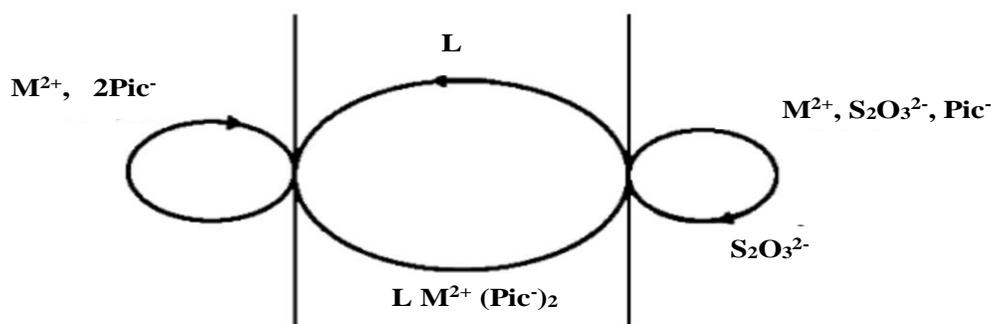
**Table 1:** The characteristics of nonionic surfactants used for the experimental part

Nonionic surfactants	Molecular formula	Molar Weight	Hydrophilic-lipophilic balance, HLB	Critical micellar concentration, CMC (mmol/L)
Triton X-100	$C_{14}H_{22}O(C_2H_4O)_{9,5}$	628	13.5	0.24
Brij 35	$C_{12}H_{25}(OCH_2CH_2)_{23}OH$	1198	16	0.06
Brij 58	$C_{16}H_{33}(OCH_2CH_2)_{20}OH$	1124	15.7	0.007
Brij 78	$C_{18}H_{37}(OCH_2CH_2)_{20}OH$	1151	15.3	0.006

The implementation of the “bulk liquid membrane” (BLM) system is relatively simple and includes a combination of three processes: extraction, diffusion and re-extraction of analyte.<sup>2</sup> Theoretical models for this type of transport were formulated already in 1973 by Reusch and Cussler<sup>8</sup> for the simple BLM systems, but they can also be used for an explanation in more complicated systems. The “carriers” of metal ions during transport experiments need to obtain adequate values of complex formation constants.

Also proper solubility in the membrane matrix, based on their lipophilicity is required to prevent "leakage" outside the membrane. These facts indicate the importance of the choice of ligands used as carriers. Since the transport occurs between two aqueous phases through the organic phase, the driving force is a gradient of metal ion concentration.<sup>9</sup>

Authors<sup>8,10</sup> assumed that the most influential process during transport experiments was the metal ions release from the complex in the membrane phase to the receiving aqueous phase through the contact surface between the two phases. Based on this assumption, authors<sup>8</sup> also proposed the possible mechanism for metal ion transport (Figure 2.)



**Figure 2:** Proposed mechanism<sup>8</sup> of metal ion transport through organic liquid membrane containing dissolved ligand (L), from source aqueous phase (which contains: metal cations,  $M^{2+}$  and counter ions picrate,  $Pic^-$ ) to receiving aqueous phase (contains stripping agent: thiosulphate ions)

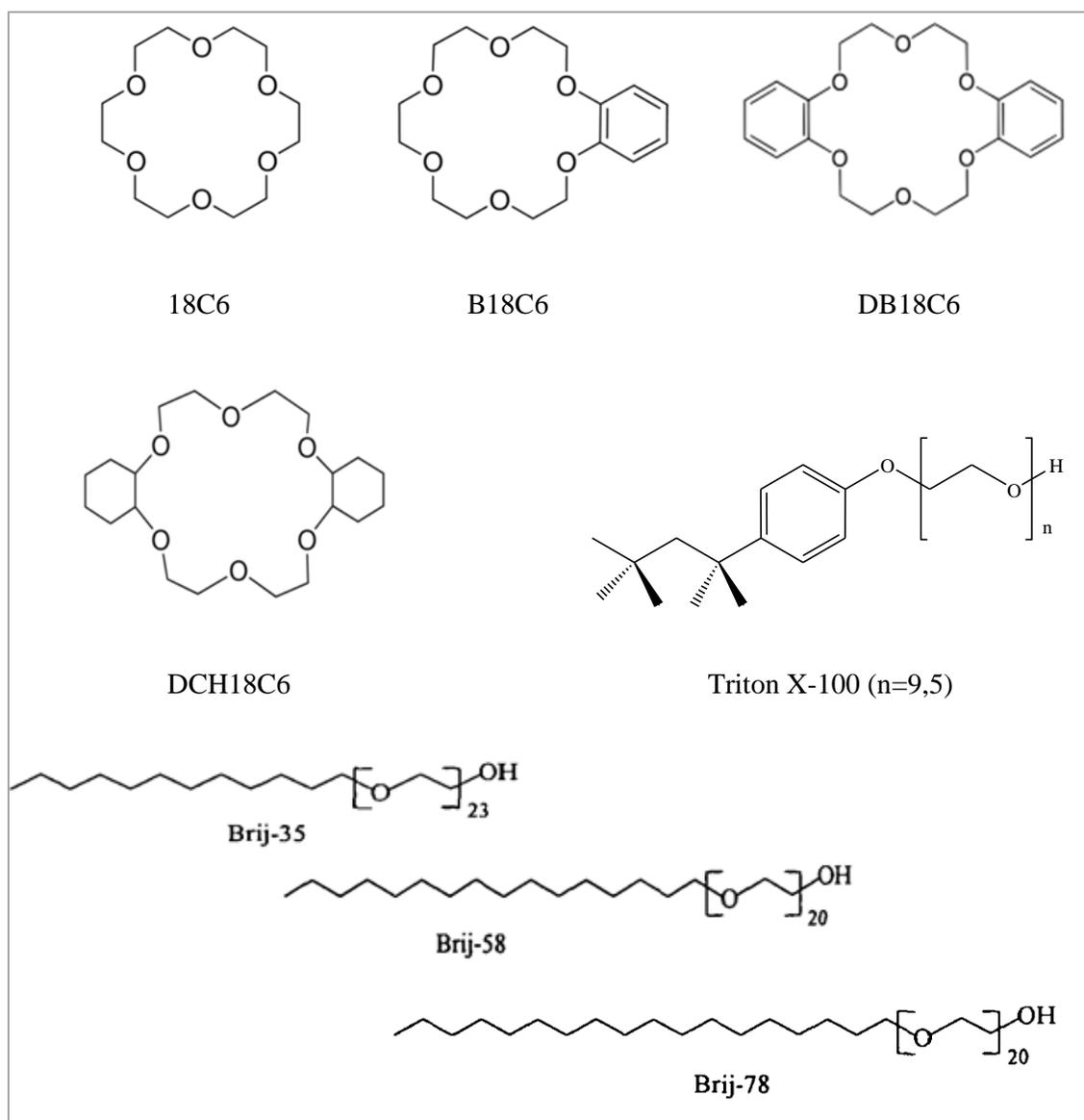
In BLM systems, selection of appropriate organic solvent is the key factor for membrane functioning. First requirement during the membrane solvent selection is high lipophilicity of solvent. The membrane should not mix with aqueous phases of BLM system. Also, proper membrane solvent should have low values of viscosity (small resistance to moving throughout the membrane) and volatility, but at the same time should enable proper distribution coefficient. Important parameter is also dielectric constant of the solvent. Authors<sup>11</sup> showed that the higher transport efficiency of Pb(II) ions in chloroform membrane compared to nitrobenzene is related to lower dielectric constant of chloroform (4.81) compared to nitrobenzene (34.82).

**Table 2.** represents the characteristics of solvents used for liquid membrane preparation in the experimental part of this paper.

**Table 2:** Solvent characteristics for liquid membrane preparation<sup>11</sup>

Solvents	Dielectric constant, $\epsilon_r$	Dipole moment, $\mu$ (D)	Viscosity, $\eta$ (mPa s)	Density, $\rho$ (g/mL)
Dichloromethane (DCM)	8.93	1.6	0.41	1.33
1,2-dichloroethane (DCE)	10.66	1.8	0.84	1.25
Nitrobenzene (NB)	34.82	4.02	2.03	1.19
Chloroform (CH)	4.81	1.15	0.56	1.49

In this paper, the influence of different nonionic surfactants on complexation process in the liquid organic membrane during transport experiments is expressed through the transport efficiency, reflecting the interactions inside the membrane. Prepared BLM "model-systems" included: known amounts of metal ions (Cd(II) and Pb(II)) and counter ions (picrate, PA) in source aqueous phase, nonionic surfactants (Triton X-100, Brij 35, Brij 58, Brij 78) dissolved in organic membrane solvent (chloroform, CH, dichloromethane, DCM and 1,2-dichloroethane, 1,2-DCE), with or without macrocyclic ligands crown ethers, CE (18-crown-6, 18C6, dibenzo-18-crown-6, DB18C6, benzo-18-crown-6, B18C6 and dicyclohexano-18-crown-6, DCH18C6) and stripping agents (thiosulphate,  $S_2O_3^{2-}$ ) in receiving aqueous phase. **Figure 3.** shows the structures of macrocyclic ligands and surfactant molecules used as carriers for cations in the experimental part of this study.



**Figure 3:** Structures of macrocyclic ligands "crown ethers" and nonionic surfactants used in the experimental work

The aim of this study was to emphasize the influence of some nonionic surfactants in membrane on lower efficiency of metal ion transport, due to the interactions between surfactants, macrocyclic ligands and cations. The efficiency of metal ion transport was monitored by measuring their concentration in the aqueous phases of BLM system after 3 hours of transport using flame atomic absorption spectrometry (FAAS).

## MATERIAL AND METHODS

Preparations of two aqueous solutions and one nonaqueous organic solution (membrane), were performed for every transport experiment, using following material.

### *Source Phase preparation:*

- Standard Cd(II) solution (1000 mg/L), (Cd(NO<sub>3</sub>)<sub>2</sub> in 0,5M HNO<sub>3</sub>), Merck
- Standard Pb(II) solution (1000 mg/L), (Pb(NO<sub>3</sub>)<sub>2</sub> in 0,5M HNO<sub>3</sub>), Merck
- C<sub>6</sub>H<sub>3</sub>N<sub>3</sub>O<sub>7</sub> (picric acid); 99%, Kemika
- Acetate buffer solution (pH = 5), prepared from CH<sub>3</sub>COOH (purris. p.a., Fluka) and NaOH (g.r., Merck)

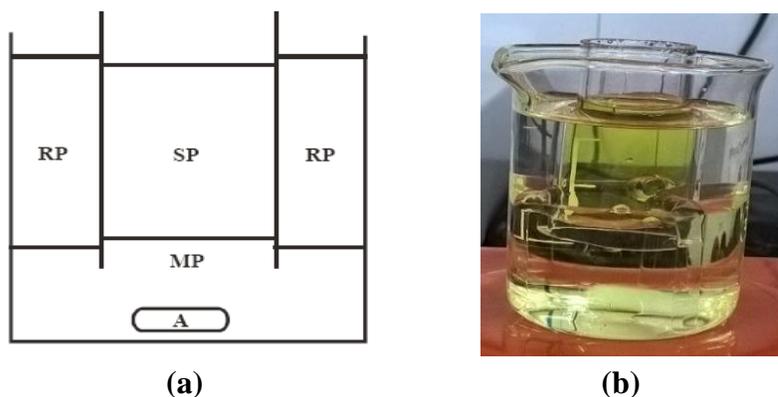
### *Membrane Phase preparation:*

- **Organic solvents:**
  - CH<sub>2</sub>Cl<sub>2</sub>, dichloromethane; p.a. Kemika
  - CHCl<sub>3</sub>, chloroform; p.a. Kemika
  - C<sub>2</sub>H<sub>4</sub>Cl<sub>2</sub>, 1,2-dichloroethane; p.a. Kemika
- **Macrocyclic ligands:**
  - C<sub>12</sub>H<sub>24</sub>O<sub>6</sub> (18-crown-6); 99%, ACROS ORGANICS, (18C6)
  - C<sub>16</sub>H<sub>24</sub>O<sub>6</sub> (benzo-18-crown-6); 99%, ACROS ORGANICS, (B18C6)
  - C<sub>20</sub>H<sub>24</sub>O<sub>6</sub> (dibenzo-18-crown-6); >99%, TCI, (DB18C6)
  - C<sub>20</sub>H<sub>36</sub>O<sub>6</sub>, (dicyclohexano-18-crown-6); >99%, ACROS ORGANICS, (DCH18C6)
- **Nonionic surfactants:**
  - C<sub>14</sub>H<sub>22</sub>O(C<sub>2</sub>H<sub>4</sub>O)<sub>9,5</sub> (Triton X-100), p.a. Sigma-Aldrich
  - C<sub>12</sub>H<sub>25</sub>(OCH<sub>2</sub>CH<sub>2</sub>)<sub>23</sub>OH (Brij 35); p.a. Sigma-Aldrich
  - C<sub>16</sub>H<sub>33</sub>(OCH<sub>2</sub>CH<sub>2</sub>)<sub>20</sub>OH (Brij 58); p.a. Sigma-Aldrich
  - C<sub>18</sub>H<sub>37</sub>(OCH<sub>2</sub>CH<sub>2</sub>)<sub>20</sub>OH (Brij 78); p.a. Sigma-Aldrich

### *Receiving Phase preparation:*

- Acetate buffer solution (pH = 5), prepared from CH<sub>3</sub>COOH (purris. p.a., Fluka) and NaOH (g.r., Merck)
- Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>, sodium thiosulphate; purrum.p.a. Sigma-Aldrich
- C<sub>10</sub>H<sub>14</sub>N<sub>2</sub>Na<sub>2</sub>O<sub>8</sub> · 2H<sub>2</sub>O, ethylenediaminetetraacetic acid disodium salt (disodium EDTA); p.a. Merck

**Transport procedure and FAAS measurements:** Cylindric glass container, i.e. "transport cell", with inner diameter of 5 cm and central glass tube (2 cm in diameter), have been used for this study (**Figure 4.**). Implementation of this type of transport cell was reported earlier.<sup>12</sup> Central tube provide physical separation of two aqueous phases: source phase, SP and receiving phase, RP. Membrane phase, MP lies under the aqueous phases and connects them. Constant stirring with a magnetic stirrer is essential to provide that contact surfaces: RP/MP/SP remain flat and well defined.



**Figure 4:** (a) Scheme of transport cell<sup>12</sup>: SP-source phase; RP-receiving phase; MP-membrane phase; A-magnetic stirrer| (b) homemade cell used in transport experiments

For this study, BLM systems have been prepared as follows: SP contained 10 mL of mixture consisted of metal ions ( $1 \cdot 10^{-3}$  mol/L) and counter-ions, picrates ( $1 \cdot 10^{-3}$  mol/L). RP contained: 30 mL of suitable stripping agent solution - thiosulphate (0,10 mol/L).

Both aqueous phases were buffered at pH=5 (acetate buffer solution was prepared and pH measured with pH meter). Membrane phase, MP contained macrocyclic ligand, L ( $1 \cdot 10^{-3}$  mol/L) dissolved in 50 mL of organic solvent, with added nonionic surfactants ( $1 \cdot 10^{-3}$  mol/L).

AAS technique with flame atomization (apparatus: Atomic Absorption Spectrometer Perkin Elmer AAnalyst 200), was implemented for measurements of metal ion concentration at wavelengths for Pb(II) and Cd(II): 261,40 nm and 326,10 nm, respectively.

Measurements were performed in both aqueous phases of transport system, after 3 hours of transport duration through the liquid membrane. Measurements were performed along with a series of standard cation solutions (prepared similarly), in order to convert the atomic absorption signals to concentration units.

## RESULTS AND DISCUSSION

In order to better understand interactions involved in the transport process, different transport experiments were carried out, based on different types of carriers for cations. For that purpose, different compositions of the membrane phases in created BLM transport systems were applied. Prior to surfactant influence study, experiments with macrocyclic ligands as carriers in membrane solvent were performed.

Surfactant influence study included two type of experiments: with surfactant carrier and with competitive carriers (surfactants and macrocycles).

**Macrocyclic carrier study:** BLM systems with membrane phase containing different macrocyclic ligands, were investigated. The obtained results (**Table 3.**) showed that among four different macrocyclic carriers, under described experimental conditions, the highest efficiencies of Cd(II) and Pb(II) transport were achieved with 18C6 as a carrier (for all used solvents: DCM, 1,2-DCE and CH). Although the ring size and cavity diameter remain the same as for 18C6 (130 pm), the presence of benzo- and cyclohexyl- groups (B18C6, DB18C6, DCH18C6) probably reduce interactions between these substituted macrocycles and cations, which lead to lower transport rate. Also, slightly higher transport rate for B18C6 compared to DB18C6 is probably related to higher rigidity of double substituted DB18C6 ring. Actually, DB18C6 has the most rigid structure among the crown ethers studied.<sup>13,14</sup> Investigating charge-transfer spectra of seven crown ethers (15C5, 18C6, B15C5, B18C6, DC18C6 and DB24C8) with picric acid in the UV-visible region in 1,2-dichloroethane, authors<sup>15</sup> suggest that the aromatic groups play an important part in the donor ability of the ethers. Also, the addition of two benzo groups (as in DB18C6), caused the value of complex stability constant to decrease due to the loss of flexibility of the ring, resulting with electron withdrawal from oxygen atoms, which consequently reduces the interactions between cations and ligands, lowering the transport efficiency. On the other hand, for DC18C6, the presence of two cyclohexyl groups cause an increase in the basicity of the oxygen atoms in comparison with DB18C6 which lead to the ability of the DC18C6 complex to adapt to different conformations as required for greater stability of the complex.<sup>15</sup>

**Table 3:** Measured content of Cd(II) and Pb(II) ions in RP after 3h of transport for different macrocyclic carriers

	Carrier	% of Cd(II) in RP				% of Pb(II) in RP			
		18C6	DB18C6	B18C6	DCH18C6	18C6	DB18C6	B18C6	DCH18C6
Solvent	DCM	48.10	38.25	40	25	70.40	36.05	38.50	30
	1,2-DCE	46.70	32.20	35.30	20.50	42.25	34.35	36.80	28.60
	CH	52.20	40.30	43.20	30.20	65.20	59.50	61.30	55.20

**Surfactant carrier study:** Experiments involved nonionic surfactants dissolved in organic solvents as carriers for Pb(II) transport. CH and DCM were selected as suitable membrane solvents based on their parameters: lower dielectric constants and lower viscosity, among others (**Table 2.**). The results (**Table 4.**) show lower transport efficiencies for surfactants, compared to macrocyclic ligands. However, the uptake from source phase is evident. Different structures of surfactants are related to different transport rates: polyethoxylated alcohols (Brij 35, Brij 78 and Brij 58) show higher concentration of cations transported into the receiving phase, for both DCM and CH membranes, compared to polyoxyethylene octylphenyl ethers (Triton X-100). This is probably related to higher number of oxygen atoms (donors) in their molecules (**Figure 3.**) compared to Triton X-100, that enable higher possibility for interactions, consequently releasing the cation into the RP. However, for dichloromethane membrane, the uptake from the source phase is evident also for Triton X-100 and comparable to other surfactants, but not the releasing to the RP. With Triton X-100, most of the removed cations from SP remain inside the membrane, which is

not the case for polyethoxylated alcohols. The results gained with chloroform membrane showed higher uptake of cations from SP, for all surfactants, but also higher level of cations remained in MP, probably due to solvent characteristics of CH compared to DCM. With chloroform membrane, the lowest transport is also evident for Triton X-100, among other surfactants. Total removal of cations is higher for chloroform membrane, compared to dichloromethane, based on the lower dielectric constant for CH (4.81) compared to DCM (8.93).

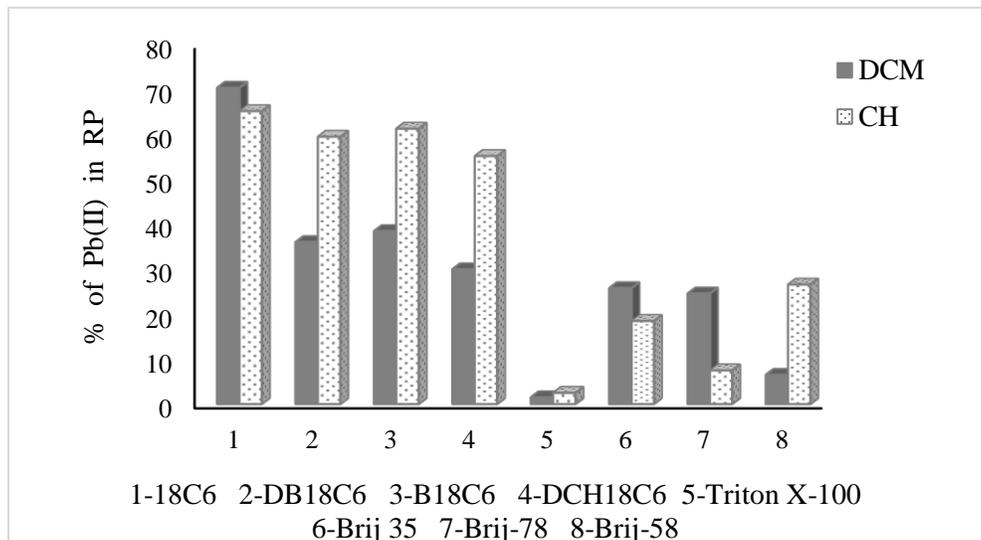
**Table 4:** Measured content of Pb(II) ions in RP after 3h of transport for different nonionic surfactants as possible carriers

Dichloromethane		% of Pb(II)			
		SP	MP	RP	removal
Surfactants	TX-100	77.5	21	1.5	22.5
	Brij 35	72	2.2	25.8	28
	Brij 78	73	2.4	24.6	27
	Brij 58	84.6	8.9	6.5	15.4
Chloroform		SP	MP	RP	removal
Surfactants	TX-100	72	25.5	2.5	28
	Brij 35	69	22.5	18.5	41
	Brij 78	56	36.5	7.5	44
	Brij 58	37.4	36	26.6	62.6

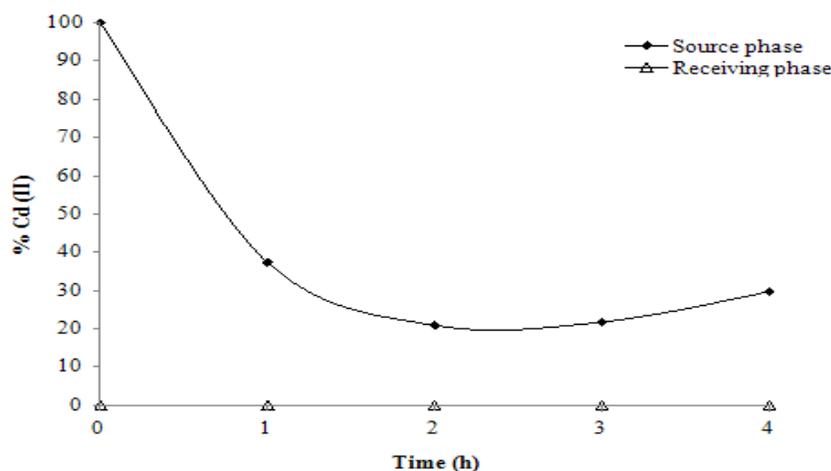
The effect of solvent is similar for Pb(II) transport with macrocyclic ligands: chloroform is more suitable membrane solvent for BLM transport under these experimental conditions (the only exception is 18C6 in DCM). However, comparing transport efficiencies for macrocyclic and surfactant carriers (**Figure 5.**) despite the significant possibility of interactions between cations and surfactants, the macrocyclic ligands show better results. Certain content of cations removed from SP and transported to RP using nonionic surfactants, shows certain possibilities for nonionic surfactants as carriers, which probably can be improved by some experimental conditions. Authors<sup>16</sup> showed that Brij 35 successfully removed Cd(II) ions through BLM transport, using EDTA in the RP. In this study, by employing EDTA as stripping agent in the receiving phase of BLM systems, increasing transport rates are evident in DCM for Triton X-100 (from 2% to 7%) and for Brij 35 (from 25.8% to 30.10 %) compared to thiosulphate.

In preliminary investigations, the percentage of Cd(II) ions was measured in both aqueous phases (RP and SP), using only TX-100 as a possible carrier in MP. Measurements were carried out every hour during the first 4 hours of transport. The results (**Figure 6.**) showed no obvious transport of metal ions into the receiving phase, despite of decreasing concentration of cations in the source phase. Obviously, the limiting step of transport is cation release at the MP/RP interface, as authors<sup>8</sup> previously predicted.

Interactions between cations and surfactants inside the membrane successfully provide cation removal from source phase, but not their transfer to the receiving phase. BLM systems with macrocyclic carriers provide cation removal from SP, complexation/decomplexation in MP, followed by cation releasing to RP, probably due to the adequate values of complex stability constants<sup>17</sup> which are required to be high enough for complexation and also low enough for decomplexation process.



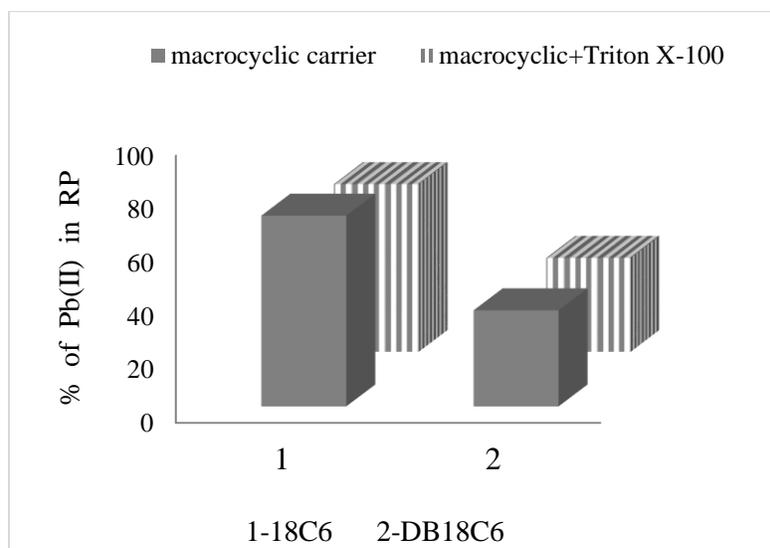
**Figure 5:** Comparison of measured Pb(II) content in RP after 3h of transport, using different carriers in BLM systems



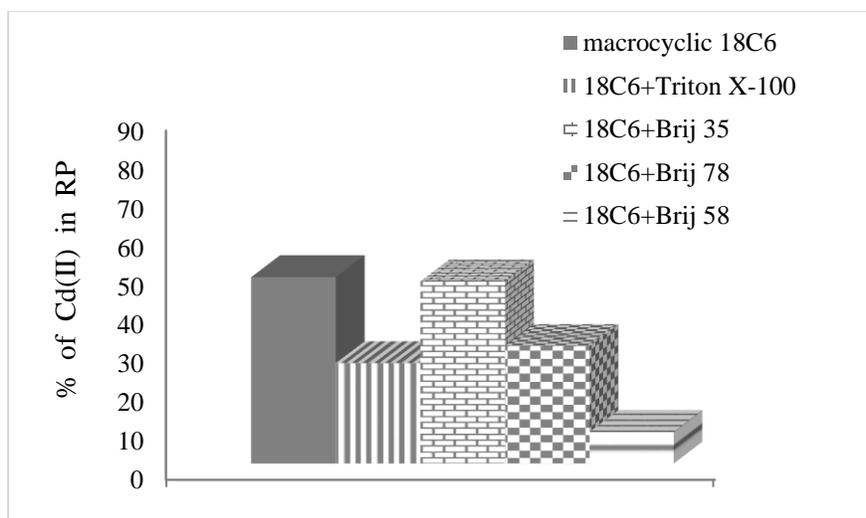
**Figure 6:** The efficiency of Cd(II) transport through liquid organic (DCM) membrane, during first 4 hours of the experiment (SP:  $1 \cdot 10^{-3}$  mol/L Pic<sup>-</sup> +  $1 \cdot 10^{-3}$  mol/L Cd(II); RP: 0,10 mol/L S<sub>2</sub>O<sub>3</sub><sup>2-</sup>; MP:  $1 \cdot 10^{-3}$  mol/L TX-100)

**Competitive carrier study:** Influence of surfactants were studied through the competitive carrier experiments, based on the interactions between surfactant, cation and macrocyclic ligands. Both carriers: macrocyclic and surfactants, were involved in process, both interacting with cations at the same time inside

the membrane, resulting with lower transport efficiencies compared to experiments with macrocyclic carriers, as it shows in **Figure 7.** for Pb(II) transport. However, results obtained for Cd(II) transport (**Figure 8.**) show transport rate for Brij 35 surfactant (47%) similar to 18C6 (48.10%), while others decrease transport efficiency.



**Figure 7:** Comparison of measured Pb(II) content in RP after 3h of macrocyclic carrier transport and transport with competitive surfactant (TX-100) carrier in dichloromethane



**Figure 8:** Comparison of measured Cd(II) content in RP after 3h of macrocyclic carrier transport and transport with competitive surfactants in dichloromethane

The influence of the competitive carrier in form of nonionic surfactant probably lead to the donor-acceptor interactions between oxygen atoms from surfactant molecules and metal cations, changing the course of cation-macrocycle complexation and resulting with the formation of a weaker complex between cation and macrocycle, which lead to lower transport. Formation of surfactant micelles which can "trap" formed

macrocyclic complex is another possible explanation for lower transport efficiencies in these BLM systems. Investigating the influence of the stearic acid, palmitic acid and oleic acid as surfactants in the membrane phase on the cation Pb(II) transport, authors<sup>18</sup> also assumed that the formation of micelles of the fatty acids in the membrane phase trap the crown-cation complex and, therefore, the transport rate of Pb(II) ion decreases in the presence of stearic, palmitic and oleic acids.

## CONCLUSION

This paper deals with the interactions between Pb(II) and Cd(II) ions, macrocyclic ligands and nonionic surfactants, inside created BLM systems, employing homemade transport cell and investigating the possibility of cation removal by suitable surfactant carrier. Numerous experiments provided results that led to conclusions:

- Significant interactions between cations and nonionic surfactants inside the membrane phase of transport systems, lead to certain removal of cations (up to 62% of Pb(II) with Brij 58 in chloroform) from the source phase into the membrane, enabling possible application of some nonionic surfactants as carriers for cations
- Limiting step in transport through the BLM systems with nonionic surfactants is cation release on MP/RP interface, due to strong interactions surfactant-cation inside the membrane
- Compared to macrocyclic carriers crown ethers, transport rates for nonionic surfactants are lower, but could be improved to certain extent by changing the experimental conditions, such as the type of stripping agent in the receiving phase
- Competitive behavior of macrocyclic ligands and nonionic surfactants during the transport process indicates that surfactant molecules possess carrier properties through donor–acceptor interactions, similar to macrocyclic ligands
- Interactions between nonionic surfactants and cations also can be explained by micellization and incorporation of cations within the micellar structures, consequently decreasing the transport efficiency

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**Corresponding author: Mersiha Suljkanović,**

**[mersiha.suljkanovic@untz.ba](mailto:mersiha.suljkanovic@untz.ba)**

Faculty of Natural Sciences and Mathematics,  
University of Tuzla, Bosnia and Herzegovina

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