Active transport of metal ions by using Schiff bases

Wail Al Zoubi*, Frouk Kandil and Khaled Chebani

Laboratory of Organic Chemistry, Department of Chemistry, Faculty of Science, University of Damascus, Syria.

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ABSTRACT

Schiff bases are aldehyde- or ketone-like compounds in which the carbonyl group is replaced by an imine or azomethine group. In this paper, the transport of metal ions from an aqueous solution into an aqueous receiving solution through a bulk liquid membrane containing Schiff bases as a carrier was described. Therefore, synthetic methods for the preparation of Schiff bases are also reviewed.

Keywords: Schiff bases, active transport, liquid membrane, liquid-liquid extraction.

*Corresponding author. E-mail: wwailalzoubi@yahoo.com, wailzoubi@yahoo.com.

INTRODUCTION

Schiff bases, named after Hugo Schiff (Schiff, 1864), are formed when any primary amine reacts with an aldehyde or a ketone under specific conditions. Structurally, a Schiff base (also known as imine or azomethine) (Figure 1) is a nitrogen analogue an aldehyde ketone in which the carbonyl group (C=O) has been replaced by an imine or azomethine group.

Schiff bases are some of the most widely used organic compounds. They are used as pigments and dyes, catalysts, intermediates in organic synthesis, as polymer stabilisers, and separation of trace amount of metal ions (Dhar and Taploo, 1982). Schiff bases have also been shown to exhibit a broad range of biological activities. Imine groups are present in various natural, natural-derived, and non-natural compounds (Figure 2) (Bringmann et al., 2004; de Souza et al., 2007; Guo et al., 2007).

SYNTHESIS OF SCHIFF BASES

The first preparation of imines was reported in the 19th century by Schiff (1864). Since then a variety of methods for the synthesis of imines have been described (Zheng et al., 2009). The classical synthesis reported by Schiff involves the condensation of a carbonyl compound with an amine under azeotropic distillation (Moffett, 1963). Molecular sieve are then used to completely remove water formed in the system (Taguchi and Westheimer, 1971). In the 1990s, in situ method for water elimination was developed, using dehydrating solvents such as tetramethyl orthosilicate or trimethyl orthoformate (Love and Ren, 1993; Look et al., 1995).

Chakraborti et al. (2004) demonstrated that the efficiency of these methods is dependent on the use of highly electrophilic carbonyl compounds and strongly nucleophilic amines. They proposed as an alternative the use of substances that function as Bronsted-Lowry or Lewis acids to activate the carbonyl group of aldehydes, catalyze the nucleophilic attack by amines, and dehydrate the system, eliminating water as the final step. Examples of Bronsted-Lowry or Lewis acids used for the synthesis of Schiff bases include ZnCl₂, TiCl₄, MgSO₄·PPTS, Ti(OR)₄, alumina, H₂SO₄, NaHCO₃, MgSO₄, Mg(ClO₄)₂, H₃CCOOH, Er(OTf)₃, P₂O₅/Al₂O₃, HCl (Chakraborti et al., 2004; Billman and Tai, 1958; White and Weingarten, 1967; Branchaud, 1983; Armstrong et al., 1997; Liu et al., 1999; Roman and Andrei, 2001; Samec and Backvall, 2002; Baricordi et al., 2004; Panneerselvam et al., 2005; Dalpozzo et al., 2006; Naeimi et al., 2006; Kulkarni et al., 2009).

In the past 12 years, a number of innovations and new techniques have been reported, including solvent-free/clay/microwave irradiation, solid-state synthesis, K-10/microwave, water suspension medium, [bmim]BF4/molecular sieves, infrared irradiation/no solvent, NaHSO₄/SiO₂/microwave/solvent free, solvent-free/CaO/microwave, and silica/ultrasound irradiation [Varma et al., 1997; Schmeyers et al., 1998; Vass et al., 1999; Tanaka and Shiraishi, 2000; Andrade et al., 2004;
R1, R2 and / or R3=alkyl or aryl

Figure 1. General structure of a Schiff base.

Figure 2. Examples of bioactive Schiff bases. The imine or azomethine group present in each molecular structure is shaded.

Va´zquez et al., 2004; Gopalakrishnan et al., 2005; Gopalakrishnan et al., 2007; Guzen et al., 2007). Among these innovations, microwave irradiation has been extensively used due to its operational simplicity, enhanced reaction rates, and great selectivity (Gedye et al., 1986). The use of microwave irradiation commenced with the independent studies of Rousell and Majetich groups (Gedye et al., 1986; Giguere et al., 1986). Microwave irradiation is less environmentally problematic than other methods because it abolishes the excessive use of aromatic solvents and the Dean-Stark apparatus for azeotropic removal of water. Another feature of this technique is that the reactions achieve high efficiency in a shorter period of time.

LIQUID MEMBRANES

A liquid membrane consists of a water immiscible organic phase containing organic extractants or carriers in a hydrophobic microporous support to facilitate selective transport. A lot of work has been done in the development of artificial membranes for the recovery or removal of a wide variety of ionic and molecular species.

If one component of a mixture moves through the membrane faster than another mixture component, these get separated. Liquids immiscible with the source and receiving phase can be used as membrane materials. As the diffusion coefficients in liquids are higher than that in polymers, a larger flux can be obtained with liquid membranes. The extraction chemistry involved in liquid membrane process is essentially the same as that in solvent extraction, but the overall process is governed by kinetic rather than equilibrium parameters (Nobel and Way, 1987).

Liquid membranes have gained wide interest since their discovery. These have been shown to have great potential for water treatment (Halwachs and Schugerl, 1980), separation of hydrocarbons (Kato and Kawasaki, 1987), hydrometallurgy (Naim et al., 1997), biotechnological and biomedical applications (Asher et al., 1980).

Liquid membrane may be broadly classified into three type: bulk, emulsion and supported liquid membranes (SLM). Bulk liquid membranes usually consist of an aqueous feed and stripping phase, separated by a water-immiscible liquid membrane phase in a U-tube. BLMs are often used to study the transport properties of novel carriers and a small membrane surface area of BLMs makes them technologically not very attractive. Emulsion liquid membranes suggested by Li (1968) have a very high surface area per unit of volume and low thickness
and it means the separation process and accumulation inside the emulsion vehicle is fast. The problem is that the vehicles have to be produced before the process; they have to be stable enough so that leakage is reduced to minimum, but still not stable so that they could be destroyed after the separation, thus allowing the removal of the transported species. As the result the process has to use several unit operations and becomes technologically not very attractive (Kocherginsky et al., 2007).

Figure 3A shows the mechanism of SLM based separation of ions. In this case, charged species A from the feed solution are selectively extracted by the carrier through organic membrane/feed interface. The carrier picks up A, moves across the membrane as a complex and finally exchanges A with the charged species C on the other side of membrane. In this case, C has the same charge as A. To preserve electrical neutrality the carrier acts as a shuttle carrying A and C in the opposite directions. That is why the process is called facilitated coupled counter-transport. The most typical example of this process is metal cation exchange with H⁺ ions, facilitated by acidic carriers. Basic carriers, like amines, can be used to carry H⁺ ions together with negatively charged ions, such as Cl⁻ in the same direction. This process is called facilitated coupled co-transport (Figure 3B) (Kocherginsky et al., 2007).

It is easy to make the feed and strip solutions with different pH, so that ion exchange processes on the two membrane surfaces will be shifted in opposite directions. This creates a concentration gradient of different forms of the carrier (with and without ions) in the membrane, and results in the directed ion flux through the membrane. Evidently the process leads to the transport of targeted ionic species across the membrane against their concentration gradient. Thus type of so-called “uphill” or active transport will continue until one driving factor (difference of chemical potentials of H⁺ ions) is balanced by difference of chemical potentials of another transported ion. If the carrier selectively extracts A in the presence of B, and then purified and concentrated in the strip solution, it is important that the process is using only chemical energy as a driving factor, and does not need transmembrane pressure or voltage (Kocherginsky et al., 2007).

The liquid membrane extraction was introduced as an alternative separation technique to the solvent extraction and to the separation by means of solid polymeric membranes (Li, 1971). Several types of liquid membrane configuration are reported (Boyadzhiev and Lazarova, 1994) differing mainly in performance of the membrane. Figure 4 shows the most common configurations: (a) the bulk liquid membrane (BLM), (b) the supported liquid membrane (SLM) and (c) the emulsion liquid membrane (ELMS). All other types of LM can be related to these ones. The BLM technique requires a simple design of the cell for the membrane process to work (Figure 4a). The membrane liquid is placed above the feed and stripping solutions, separated with a solid barrier, thus being in contact with both of these solutions. In the SLM (Figure 4b),
Figure 4. Liquid membrane types (a) bulk membrane, (b) supported liquid membrane, (c) emulsion liquid membrane.

a porous, solid barrier, is in contact with both of these solutions. In the SLM (Figure 4b), a porous, solid and inert, support is required to hold liquid within the membrane phase and fixed between the two aqueous, feed and stripping, solutions. ELMS are based on emulsion of the aqueous/organic/aqueous type. To obtain this, a fine emulsion of the stripping phase in the membrane phase is produced and stabilized by a surfactant. The resulting water-in-oil emulsion is then dispersed by stirring in the feed solution to create a double emulsion (Figure 4c).

Thus, a large interface area between the feed solution and the emulsion globules, and even a larger surface area of the encapsulated stripping solution, accelerates the transport of selected species (Bukhart, 2007).

This setup has a very thin membranes and a large surface area to volume ratio, which enhances the transport rate of the membrane. Concentrations in the receiving phase volume, which occurs whenever the organic phase emulsion is added to an even larger quantity of source phase (Bukhart, 2007).

In bioanalysis, membrane techniques have been applied to the determination of drugs and also to other compounds in biological fluids such as blood plasma and urine (Bukhart, 2007).

**PREVIOUS STUDIES ON METAL ION SEPARATION BY LM**

During the last three decades, an increased interest has been shown in trace elements in water. Considerable success has been achieved in the development of artificial membranes for the recovery or removal of a wide variety of ionic and molecular species, so that LMs have found their major application in separation technology (Bachiri et al., 1996).

Notably, they offer the advantage to perform the extraction and the stripping in one single step. The literature about the liquid membrane has been mainly devoted to their use in the field of chemical separation (Oleiji et al., 1997; Saito, 1998; Li et al., 1998; Guyon et al., 1999; Breemboek et al., 1998; Shirai et al., 1995). More fundamental studies were devoted to a better understanding of the nature of ion transfer processes taking place at the membrane interface.

Selective separation of a given metal ion from a complex mixture of other ionic species is of increasing importance in industrial and analytical chemistry and separation sciences. In most cases, various interfering species must be removed and/or the species of interest must be enriched before detection. Carrier mediated transport through liquid membrane is well known as one of the most powerful tools for such concentration, separation and recovery processes (Shirai et al., 1995). An important advantage for the use of this procedure is that in the liquid membrane technology, the extraction, stripping and regeneration operations are combined in one single step.

Owing to their coordinating ability with a variety of metal ions, Schiff base ligands have been involved in various analytical investigations for many years. As instance, they are a category of important sensory molecules for fabricating cation (Masniahizadeh et al., 2007; Gupta et al., 2006; Ardakani et al., 2005) and anion (Sadeghi et al., 2006; Shamsipur et al., 2001) selective electrodes. Octadecyl disks modified by Schiff base ligands have been used for enrichment and separation of trace amount of metal ions (Shamsipur et al., 2000; Shamspur et al., 2003). Shemirani et al. (2003) studied the application of bis(2-methoxybenzaldehyde) ethylenediimine as a complexing agent for Cr(III) ions and a subsequent entrapment of these complexes in surfactant micelles for pre-concentration and separation of chromium ions. In addition, a variety of Schiff base ligands of Type N2 (Oshima et al., 2001; Oshima et al., 2002; Oshima et al., 2003) and N2O2 (Hirayama et al., 1997; Kara and Alkan, 2002) were used as extractant in
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H\text{(SDS across a dichloromet buffer (pH 7) into the receiving phase including HNO}_3\text{.)}

The transported amount of copper ions from ammonium the kinetics of decomplexation at the stripping interface.

to significantly the proces

dodecysulfate (SDS), an anionic surfactant, to the transported in comparison with those in the single processes towards copper ions were tested by performing the competitive transport experiments on the mixture containing Pb^{2+}, Ni^{2+}, Cd^{2+}, Zn^{2+} and Co^{2+} ions. Although N\text{$_2$O}_2 possesses higher transport efficiency with respect to that of N\text{$_3$O}_2, both ligands present adequate selectivity for separation of Cu (II) ions (Massoumeh and Reza, 2009).

Selectivity of the transport experiments using N\text{$_2$O}_2 and N\text{$_3$O}_2 carriers under similar experimental conditions towards copper ions over lead, nickel, cobalt, cadmium and zinc ions from binary mixtures and a mixture containing all of the mentioned ions was evaluated (Table 1). The results present the suitable selectivity of the studied carriers towards copper ions over the examined ions. It is noteworthy that, the presence of other metal ions in the mixture decreases the percentage of copper transported in comparison with those in the single species experiments. This is probably due to a multi-ion competition or crowding effect (Alguacil et al., 2004; De Gyves and Rodriguez de San, 1999; Parinejad and Yaftian, 2007).

So far as for transition and heavy metal ions, a number of carriers for Cu (II) that is both vital and toxic for many biological system have been reported (Kubo et al., 1998; Safavi and Rastegarzadeh, 1995; Maruyama et al., 1981; N\text{$_3$O}_2, at 20°C, was found to be 90.6 (±0.7)% and 97.4 (±0.4)% after 4 h, respectively. The selectivity of the processes towards copper ions were tested by performing the competitive transport experiments on the mixture containing Pb^{2+}, Ni^{2+}, Cd^{2+}, Zn^{2+} and Co^{2+} ions. Although N\text{$_2$O}_2 possesses higher transport efficiency with respect to that of N\text{$_3$O}_2, both ligands present adequate selectivity for separation of Cu (II) ions (Massoumeh and Reza, 2009).

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Kishii et al., 1985; Hiratani et al., 1990). These methods for the specific transport of Cu (II) ions across a liquid membrane have the drawbacks of a slow rate of transport or a lack of high selectivity and efficiency. For example, it has been reported (Salavi and Rastegarzadeh, 1995) that the urea-containing octameric oligomer [-CH2CH2N(CONHph)-]6 provide the selective passive transport of copper ion through a liquid membrane. However, the flux of transport was small; after 24 h only 37% of total copper ion was transported. The reported carriers such as 6-amino-6-dodecylamino-2,2-bipyridine (Maruyama et al., 1981) and N,N-bis(8-quinolyl) glutaramide (Kishii et al., 1985) showed that after 20 and 48 h only 50 and 63% of copper (II) were transported to the receiving phase, respectively. Therefore, the development of effective and specific systems for studying of transport of metal ions, and in particular Cu(II), is still a challenging task form both the practical and theoretical viewpoints.

The transport of Cu(II) through a chloroform bulk liquid membrane containing a new tetradentates Schiff base; N,N-bis(salicylidene)-naphthylene-1,8-diamine (NBSND) (Figure 6) as an excellent synthetic carrier was studied. Although in the case of acidic receiving phase without any surfactant, only a few percent of copper had been transported into the receiving phase after several hours, the addition of sub millimolar of an anionic surfactant such as sodium dodecyl sulfate (SDS) into the receiving phase increases the percent of copper transported to more than 97%. This transport is very selective to copper over alkali, alkaline earth and several transition and heavy metal ions (Rouhollahi et al., 2007).

The selectivity of the membrane system proposed was studied under optimum conditions by undertaking competitive transport experiments with equimolar concentrations of different alkali, alkaline earth, transition and heavy metal ions. The results obtained are summarized in Table 2. As can be seen, among a wide variety of cations tested, only Ni2+ and Mn2+ ions shows some interfering effect on the transport of Cu2+ ions(mixture number 4) and the system is very selective to Cu2+ ion over other cations (Rouhollahi et al., 2007).

Conditions, source phase, 5 ml of 1.0 × 10−4 M of each cation and 0.1 M ammonia at pH; liquid membrane phase, 20 ml of 8.0 × 10−5 M NBSND in chloroform; receiving phase, 10 ml solution of 5.0 × 10−4 M SDS and 0.1 M nitric acid

The ability of pyrazole (Figure 7) and its derivatives to act as ligands with sp2 hybrid nitrogen donors is evident from the large number of articles, several of them being reviews as the synthesis of a new tetropyrazolic macrocyclic structure with a functionalised arm was described. The complexing properties of this new compound towards alkali metal ions (K+, Na+, Li+) were studied by liquid–liquid extraction and liquid membrane transport processes (Radi et al., 2006).

The competitive metal ion extraction and transport of Cu(II), Ni(II), Zn(II) and Mn(II) with a S-N donor, that is, 5-methyle-[thiophen-2-ylmethyl-en-amino]-3-thio-oxo-1,2,4-triazol-5-one (ATTT) and oxygen donor, phthalic dicarboxaldehyde (PHDC) compounds was examined and compared each other. Although the extraction and transport behavior of Cu(II) and Zn(II) with both ATTT and PHDC ligands is fundamentally similar, but the transport efficiency for Cu(II) is much better than Zn(II) ion. The transport and extraction results closely parallel for the cations using the present ligands. The experiments were buffered (acetic acid/sodiumacetate and formic acid/sodiumformate) at pH 3 to 7. The concentrations in the all transport and extraction experiments for the cations and ligands were 0.01 M and 1.0 × 10−3 M, respectively (Nezhadali et al., 2008).

5,6,14,15-Dibeno-1,4-dioxo-8,12-diazacyclopentadeca-5,14-diene (DBDA15C4) (Figure 8) as a mobile carrier and histidine as a stripping agent were used for the selective uphill and proton driven transport of Zn2+ ions through a bulk liquid membrane. A study of different parameters on zinc transport has been carried out. This includes the pH of the feed phase, amount of DBDA15C4 in the liquid membrane, type and concentration of acid and amino acid in the strip phase and transport. In the optimum procedure conditions, the maximum transport of Zn2+ ions at 3 h was observed (96.2 ± 1.2%). With this system, Zn2+ as Zn-histidine complex could be separated from Cu2+, Cd2+, Pb2+, Mn2+, Cr3+, Al3+, Co2+, Ni2+, Ca2+, Mg2+ and Fe3+. The transport mechanism of this system has been described (Fakhari et al., 2006).

The selectivity of the membrane system was studied at optimum conditions for the transport of Zn2+ ion over other cations, which were initially present with Zn2+ in equimolar concentrations. Table 3 shows the percentage of cations transported into strip phase and remained in feed phase in the presence and absence of histidine. As it is seen, the presence of histidine in the strip phase could largely increase the selectivity of Zn2+ transport.
Table 2. Amount of cation transported from various cation mixtures through the membrane.

<table>
<thead>
<tr>
<th>Cation</th>
<th>Percentage transported into receiving phase</th>
<th>Percentage remaining in source phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixture 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu(^{2+})</td>
<td>99</td>
<td>0</td>
</tr>
<tr>
<td>K(^+)</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Ca(^{2+})</td>
<td>1</td>
<td>98</td>
</tr>
<tr>
<td>Mg(^{2+})</td>
<td>0</td>
<td>99</td>
</tr>
<tr>
<td>Mixture 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu(^{2+})</td>
<td>97</td>
<td>2</td>
</tr>
<tr>
<td>Mn(^{2+})</td>
<td>12</td>
<td>84</td>
</tr>
<tr>
<td>Cd(^{2+})</td>
<td>1.2</td>
<td>96</td>
</tr>
<tr>
<td>Mixture 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu(^{2+})</td>
<td>95</td>
<td>4</td>
</tr>
<tr>
<td>Ni(^{2+})</td>
<td>15</td>
<td>82</td>
</tr>
<tr>
<td>Co(^{2+})</td>
<td>3</td>
<td>94</td>
</tr>
<tr>
<td>Mixture 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu(^{2+})</td>
<td>98</td>
<td>0</td>
</tr>
<tr>
<td>Pb(^{2+})</td>
<td>0</td>
<td>98</td>
</tr>
<tr>
<td>Zn(^{2+})</td>
<td>1</td>
<td>97</td>
</tr>
<tr>
<td>Hg(^{2+})</td>
<td>0</td>
<td>99</td>
</tr>
</tbody>
</table>

Figure 7. New tetrapyrazolic macrocycle 4 and literature compounds A and B.
This high affinity of histidine for Zn$^{2+}$ ion over other cations have been reported (Tanaka and Shiraishi, 2000; Andrade et al., 2004). This observable fact is based on the specific interaction of imidazole group of histidine with the Zn$^{2+}$ ion (Table 3) (Lipscomb and Str"ater, 1996; Brown et al., 1983).

New Schiff base ($N_2O_2$) (Figure 9) containing nitrogen-oxygen atoms was designed and synthesized by the reaction of 5-amino-2-methoxy phenol with terephthalaldehyde. Transportation of copper ions across bulk chloroform containing ($N_2O_2$) as carrier has been studied. The selectivity of the processes toward copper ions were tested by performing the competitive transport experiments on the mixture containing Pb$^{2+}$, Ni$^{2+}$, Cd$^{2+}$, Zn$^{2+}$ and Co$^{2+}$ ions. The amount of copper transport through the liquid membrane after 90 min 99% at 25°C was studied (Zoubi et al., 2011). Selectivity of the transport experiments using $N_2O_2$ carrier under similar experimental conditions toward copper ions over lead, nickel, cobalt, cadmium and zinc ions from binary mixtures was evaluated (Table 4). It is noteworthy that the presence of other metal ions in the mixture decreases the percentage of copper transported in comparison with in single species experiments. This is probably due to a multi-ion competition or crowding (Alguacil et al., 2004; De Gyves and Rodriguez de, 1999; Parinejad and Yaftian, 2007).

New Schiff base ($H_2L$) containing nitrogen-sulfur-
oxygen atoms was synthesized by reaction of α,α'-bis(5-bromo-2-carboxyaldehyde phenoxy)-1.4-xylene with aminothiophenol (Figure 10). Transport of copper ion across a bulk chloroform membrane containing Schiff base ligand (H$_2$L) as carrier has been studied. The parameters influencing the transport efficiency such as composition of receiving phase, pH of the feed phase, carrier concentration in the membrane, EDTA concentration in the receiving phase, effect of temperature and time dependency of the process were studied and discussed (Zoubi et al., 2012).

**MECHANISM OF METAL IONS TRANSFER IN LIQUID MEMBRANE**

The copper ions are transported from source phase to the receiving phase through chloroform with simultaneous counter-transport of protons. The Cu$^{2+}$ transport can be explained as follows: at source phase/membrane interface, the carrier complex of copper ion forms uncharged complex CuL. At this stage, the carrier splits off protons into the source phase. The formed complex diffuses across the membrane and at the membrane/receiving phase interface, the release of the Cu$^{2+}$ ion into the receiving phase occurs via the decomposition of the complex. At this stage, the carrier associates with proton from the receiving phase releasing Cu$^{2+}$ ion into the receiving phase. The free carrier diffuses back across the membrane to the source phase/membrane interface, where the cycle starts again.

**Conclusions**

The transport of alkali metal cations through bilayers presents a challenge that nature has met through millions of years of evolution.

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**Table 4.** Percentage of transported copper, zinc, cobalt, cadmium, nickel, and lead ions from its mixtures by N$_2$O$_2$.

<table>
<thead>
<tr>
<th>Mixture</th>
<th>M$^{2+}$</th>
<th>Transported value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix. 1</td>
<td>Cu$^{2+}$</td>
<td>88.2</td>
</tr>
<tr>
<td></td>
<td>Zn$^{2+}$</td>
<td>9</td>
</tr>
<tr>
<td>Mix. 2</td>
<td>Cu$^{2+}$</td>
<td>81.7</td>
</tr>
<tr>
<td></td>
<td>Co$^{2+}$</td>
<td>13.6</td>
</tr>
<tr>
<td>Mix. 3</td>
<td>Cu$^{2+}$</td>
<td>88.2</td>
</tr>
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<td>Pb$^{2+}$</td>
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<td>Mix. 4</td>
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<td>Ni$^{2+}$</td>
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<td>Mix. 5</td>
<td>Cu$^{2+}$</td>
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<td>Cd$^{2+}$</td>
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Uphill transport of Cu(II) against its concentration gradient is easily performed with the illustrated system (Figure 11). Also, this study demonstrates the usefulness of the liquid membrane technique for making it possible to combine extraction and stripping operations in a single process and reducing the solvent inventory requirements. In conclusion, this system has the advantages of high precision, efficiency, simplicity and speed.

In conclusion, we have reviewed prepared Schiff bases, which have an unusual aptitude for formation of complexes with metal ions. It has been demonstrated that these Schiff bases transport metal ions. Also the present study demonstrates that the Schiff bases are an excellent carrier for selective and efficient transport of metal ions.

Uphill transport of M$^{n+}$ against its concentration gradient is easily performed with the above system. Also, this study demonstrates the usefulness of the liquid membrane technique for making it possible to combine extraction and stripping operations in a single process and reducing the solvent inventory requirements.

REFERENCES


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