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ORIGINAL ARTICLE

Synthesis and characterization of new macrocyclic schiff bases by the reaction of: 1,7-Bis (6-methoxy-2-formylphenyl)-1,7-dioxaheptane and their use in solvent extraction of metals

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KEYWORDS

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Abstract Two new macrocyclic Schiff bases (II) and (III) containing nitrogen–oxygen donor atoms were designed and synthesized by reaction between diethylene triamine or 2,2′-(ethylenedioxy) bis (ethylamine) and the intermediate compound: 1,7-bis (6-methoxy-2-formylphenyl)-1,7-dioxaheptane (I). Identification of these macrocyclic Schiff bases: 1,15,18,21,35,38-hexaaza-7,9;27,29-dibenzo-[3,4;12,13;23,24;32,33-tetra-(6′-methoxy phenyl)]-5,11, 25,31-tetraoxacyclotetracontan-1,14,21,34-tetraene. (II) 1,15,24,38-Tetra aza-7,9; 30,32-dibenzo-[3,4;12,13;26,27;35,36-tetra-(6′-methoxy phenyl)]-5,11,18,21,28,34,41,44-octaoxacyclo-hexatetracontan-1,14,24,37-tetraene. (III) was determined by (LC–MS), (IR), (^{1}H NMR) spectroscopy, and microanalysis (C,H,N). The liquid–liquid extraction of metal picrates, such as Ag^+, Cu^{2+} and Ni^{2+} from aqueous phase to organic phase was carried out using the novel ligands. The effect of chloroform and dichloromethane as organic solvents over the metal picrate extractions was investigated at 25 ± 0.1 °C by using atomic absorption spectrometer. The composition of the extracted Ag^+ complex was (1:2) (L:M) and Cu^{2+} complex was (1:1) (L:M) for ligand (III).

1. Introduction

Polyaza macrocycles with large cavities have received recent interests as inorganic cation receptors (Chaudhary et al., 2003). The cyclic arrangement of a large number of donor atoms and the flexibility of these ligands make them good hosts for ion complexes (Walkowiak et al., 1987). Also used as spectrophotometric analytical reagents for example, metal ions have enormous ion importance in many biological processes (Saleh, 2005). Especially, heavy metal ions are effective enzyme inhibitors exerting toxic effects on the living system

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(Christian, 1996). Therefore, separation and determination of toxic metal ions, such as mercury, lead, and cadmium in environmental sources play an important role for a healthy life (Ibrahim et al., 2006). Although the macrocyclic compounds are mainly oxygen, sulfur, and nitrogen types, the macrocyclic compounds used in solvent extraction were mostly of the oxygen type (Ummuhan and Hakan, 2006). A number of methods for the preparation of the large polyaza macrocyclic compounds have been reported. The most common synthetic procedure requires the use of *N*-tosyl groups to protect and activate the nitrogen atoms in the cyclization step (Richman and Atkins, 1974). Ring closure occurs by a condensation reaction of *N*-tosylated polyamines with the appropriate ditosylate ester or dihalide in DMF in the presence of a base (Iwata and Kuzuhara, 1989; Habibi and Izadkhan, 2004). These reactions allow the production of polyaza macrocycles in moderate yields (Atkins et al., 1978), but removing the *N*-tosyl groups requires drastic conditions and is not always straight forward. Another cyclization process uses the template ring closure formation of the cyclic di-or tetra Schiff base. This is a simple process, but it is often difficult to choose the correct template metal ion or to predict certain ring contraction reactions where the template cation does not coordinate with all of the ring nitrogen atoms (Cabral and Murphy, 1984). In some cases, the reduction of the cyclic Schiff base and the removal of the template ion have been difficult (Drew et al., 1987). A non template method for the formation of the macrocyclic poly Schiff bases has also been studied. This procedure often gave a polymeric material beside cyclization reaction, while there is no need to remove a metal ion (Sone et al., 1989; Krzysztof et al., 1991). In the present work we used a non template method for the formation of the two novel macrocyclic Schiff bases: (II) and (III) then were used for the transfer of various metal ions from the aqueous phases into the organic phases in liquid–liquid extraction systems.

2. Experimental

2.1. Materials and method

Chloroform, dichloromethane, dimethyl formamide, picric acid, methanol $Cu(NO_3)_2{\cdot}3H_2O$, $Ni(NO_3)_2{\cdot}6H_2O$, $Ag(NO_3)$, K_2CO_3 were obtained from Merck. Diethylene triamine, 2,2′-(ethylenedioxy) bis(ethylamine), α,α′-dichloro-m-xylene and o-vanillin were obtained from Sigma–Aldrich. IR spectra were obtained on the Jusco 300 FT-IR Spectrometer with the samples in the compressed KBr discs. Mass spectra of the ligand were measured on a micro mass Quattro LC–MS/MS Spectrometer. ^{1}H NMR spectra were recorded at ambient Broker DT-400 Spectrometer using $CDCl_3$ with DMSO–DMF as the internal standard. A Hitachi Model 180-80 Atomic absorptions Spectrometer (acetylene/air flame) was used to determine the concentration of metal ions.

2.2. Synthesis of: 1,7-Bis (6-methoxy-2-formylphenyl)-1,7-dioxaheptane (I)

To a stirred solution of o-vanillin (3.04 g, 0.02 mol) and K_2CO_3 (1.38 g, 0.01 mol) in DMF (50 ml) α,α′-dichloro-m-xylene (1.75 g, 0.01 mol) in DMF(10 ml) was added dropwise; the reaction was continued for 10 h at 150–155 °C and then for 5 h at room temperature. After the addition was completed, 20 ml of distilled water was added (Salih et al., 2008). This solution was extracted with 100 ml of dichloromethane; oily product was obtained. Yield: (3.3 g, 82%), R_f: 0.6 2 (ethyl acetate).

(LS–MS): $m/z = 406$. IR (KBr pellets, cm^{-1}): 3050 (aromatic –CH), 2930–2887 (aliphatic –C–H), 1690 $(C{=}O)_{str}$, 1482–1475 (aromatic C=C), 1289–1235 (Ar–O), 1225 (O–CH_3), 1130–1100(R–O), 757 (substituted benzene).

2.3. Synthesis of: 1,15,18,21,35,38-hexaaza-7,9; 27,29-dibenzo-[3,4;12,13; 23,24;32,33-tetra-(6′-methoxyphenyl)]-5,11,25,31-tetraoxacyclotetra contan-1,14,21,34-tetraene (II)

The macrocyclic (II) was prepared by the dropwise addition of a solution of the diethylene triamine (0.206 g, mmol) in methanol (40 ml) to a stirred solution of compound (I) (0.81 g, 2 mmol) in methanol (60 ml). After the addition was completed, the stirring was continued for 10 h, an oily product began to separate from the solution. It was purified by washing with ethanol. The large macrocyclic product was pale yellow oil. Yield: (1.0 g, 74%). R_f: 0.81 (chloroform). (LS–MS): $m/z = 946$. IR (KBr pellets, cm^{-1}): 3200 (–N–H), 3080 (aromatic–CH), 2920, 2847 (aliphatic –C–H), 1640 $(CH{=}N)_{str}$, 1488–1460 (aromatic C=C), 1287, 1238(aromatic –O), 1220 (O–CH_3), 1180, 1130(R–O), 758 (substituted benzene). ^{1}H NMR (DMSO-d6): 8.39 (s, CH=N), 7.10–8.01 (m, Ar–H), 4.30 (t, –O CH_2–), 3.92 (t, CH_2–O– ph), 3.5 2 (s, O–CH_3), 3.7 2–3.8 8 (t, CH_2–N–), 2.9 2 (t, CH_2–NH–), 2.1 2 (m, –NH–).

Anal. Calc. For $C_{56}H_{62}N_6O_8$: C, 71.03; H, 6.55; N, 8.87; O, 13.53. Found: C, 70.53; H, 6.25; N, 8.97; O, 14.23. $[\alpha]_D^{20.5} = -24.5$ ($c = 0.017$, CH_3OH).

2.4. Synthesis of: 1,15,24,38-tetra aza-7,9; 30,32-dibenzo-[3,4;12,13; 26,27; 35,36-tetra-(6′-methoxy phenyl)]-5,11,18,21,28,34,41,44-octaoxa cyclo-hexatetracontan-1,14,24,37-tetraene (III)

The macrocyclic (III) was prepared by the dropwise addition of a solution of the 2,2′-(ethylenedioxy) bis(ethylamine) (0.74 g, 5 mmol) in methanol (60 ml) to a stirred solution of compound (I) (2 g, 5 mmol) in methanol (60 ml). After the addition was completed, the stirring was continued for 10 h, an oily product began to separate from the solution. It was purified by washing with ethanol. The large macrocyclic product was pale yellow oil. Yield: (3 g, 60%). R_f: 0.6 1 (dichloromethane). (LS–MS): $m/z = 1036$. IR (KBr pellets, cm^{-1}): 3026 (aromatic –CH), 2888, 2847 (aliphatic –C–H), 1650 $(CH{=}N)_{str}$, 1488, 1460 (aromatic C=C), 1287, 1238 (aromatic –O), 1222 (O–CH_3), 1180, 1130(R–O), 754 (substituted benzene). ^{1}H NMR (DMSO-d6): 8.23 (s, CH=N), 7.10 –7.42 (m, Ar–H), 4.20 (t, O–CH_2), 3.42(t, CH_2-O-ph), 3.42(s, O–CH_3), 3.6–3.7 (t, CH_2–N=).

Anal. Calc. For $C_{60}H_{68}N_4O_{12}$: C, 69.49; H, 6.56; N, 5.41; O, 18.53. Found: C, 69.67; H, 6.82; N, 5.23; O, 18.27 $[\alpha]_D^{20.5} = -28.5$ ($c = 0.013$, CH_3OH).

3. Solvent extraction

Transition metal picrates were prepared by the stepwise addition of a 1×10^{-2} M of metal nitrate solution to a

1.25×10^{-4} M aqueous picric acid solution and by shaking at 25 °C for 1 h. An organic solution (5 ml) of ligand (1.25×10^{-5} M) and an aqueous solution (5 ml) containing metal picrate (1.25×10^{-4} M) were shaken for 1 h. The resulting mixtures were allowed to stand for at least 1 h in order to complete the phase separation. The concentration of cation in aqueous phase was determined by an atomic absorption spectrometer. The extractability was calculated from Eq. (1).

$$\%E = [(A_0 - A)/A_0] \times 100 \qquad (1)$$

Where A_0 is the concentration of cation in aqueous phase before extraction, A is the concentration of cation in aqueous phase after extraction.

The dependence of the distribution ratio D of the cation between the aqueous phase and the organic phase upon the ligand concentration was examined.

The general extraction equilibrium is assumed to be given by Eq. (2)

$$M^{n+}_{aq} + npic^{-}_{aq+m}L_{org} = [M(Pic)_n(L)_m]_{org} \qquad (2)$$

The overall extraction equilibrium constant is expressed as Eq. (3)

$$K_{ex} = \frac{[M(Pic)_n(L)_m]_{org}}{[M^{n+}]_{aq}[pic^{-}]^{n}_{aq}[L]^{m}org} \qquad (3)$$

The distribution ratio D would be defined by Eq. (4)

$$D = \frac{[M(Pic)_n(L)_m]_{org}}{[M^{n+}]_{aq}} \qquad (4)$$

It follows that

$$D = K_{ex}[pic^{-}]^{n}_{aq}[L]^{m}org \qquad (5)$$

$$\mathrm{Log}\, D = n\log[Pic] + \log K_{ex} + m\log[L] \qquad (6)$$

The extraction equilibrium constant (log K_{ex}) between an aqueous solution of metal picrates and an organic solution of Schiff base: cation complex can be calculated from the equation (6) (Halit et al., 2004).

Table 1 The extractability of aqueous metal picrates for the macrocyclic Schiff bases (II) and (III) in to organic phase.

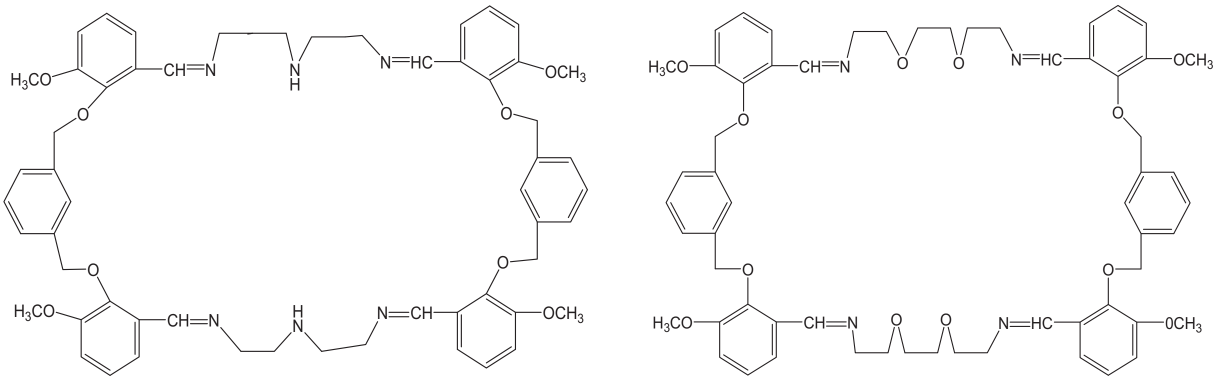
Metal ion	Extractability[a,b] (%)		Extractability[a,c] (%)	
	(II)	(III)	(II)	(III)
Ag^{+}	72.0 ± 0.3	84.2 ± 0.1	22.4 ± 0.1	42.2 ± 0.3
Cu^{2+}	18.1 ± 0. 2	30.1 ± 0.3	6.1 ± 0.3	24.4 ± 0.2
Ni^{2}	14.3 ± 0.2	17.0 ± 0.3	5.4 ± 0.3	23.5 ± 0.5

[a] Temperature: 25.0 ± 0.1 °C aqueous phase (5 ml); [pic] = 1.25×10^{-5} M, organic phase (5 ml) [L] = 1.25×10^{-4} M.
[b] Defined as percent extracted into dichloromethane phase.
[c] Defined as percent extracted into chloroform phase.

Table 2 The selectivity of silver picrate over the other metal picrates for the macrocyclic Schiff bases (II) and (III).

Metal ion	Selectivity[a] D_{Ag+}/D^{n+}_{m}		Selectivity[b] D_{Ag+}/D^{n+}_{m}	
	(II)	(III)	(II)	(III)
Cu^{2+}	9.1 ± 0.2	9.9 ± 0.3	4.8 ± 0.3	2.3 ± 0.2
Ni^{2+}	10.7 ± 0.1	14.4 ± 0.5	4.8 ± 0.3	2.4 ± 0.5

[a] Calculated for dichloromethane as organic solvent phase.
[b] Calculated for chloroform as organic solvent phase.



(II) **(III)**

Figure 1 Structure of the macrocyclic Schiff bases (II), and (III).

4. Result and discussion

4.1. Macrocyclic Schiff bases

In this work, we have found that in the reaction between diethylene triamine or 2,2′-(ethylenedioxy) bis(ethylamine) and dialdehyde (I) was (2:2) Schiff base macrocycle is formed as the major product (II) and (III). The macrocyclic ligands were characterized by mass spectrometry, IR and ^{1}H NMR spectroscopy. The mass spectra of (II) and (III) play an important role in conforming the (2:2) (dialdehydes:diamine). The macrocyclic Schiff base 1,15,18,21,35,38-hexaaza-7,9; 27,29-dibenzo-[3,4;12,13;23,24;32,33-tetra-(6′-methoxy phenyl)]-5,11,25,31-tetraoxacyclotetracontan-1,14,21,34-tetraene (II) was synthesized by the reaction of 1,7-bis (6-methoxy-2-formylphenyl)-1,7-dioxaheptane (I) with di ethylene triamine in methanol, the IR spectrum of ligand (II) shows a $\nu(\mathrm{CH{=}N})_{\mathrm{str}}$ peak at 1640 cm^{-1}, a ν(–N–H) peak at 3200 and the absence of a $\nu(\mathrm{C{=}O})$ peak at around 1690 cm^{-1} for (I) is indicative of Schiff base condensation. The mass spectra show a molecular peak at m/z = 406 for (I) and m/z = 946 for (II), which are confirmed by the formation of macrocyclic Schiff base (II), the NMR spectrum of ligand (II) exhibits amine protons at 3.73–3.87 ppm and imine protons at 8.39 ppm, but no signals corresponding to the formyl protons are presented. The macrocyclic Schiff base 1,15,24,38-tetra aza-7,9; 30,32-dibenzo-[3,4;12,13;26,27;35,36-tetra-(6′-methoxyphenyl)]-5,11,18,21,28,34,41,44-octaoxa cyclo-hexatetracontan-1,14,24,37-tetraene (III) was synthesized by the reaction of 1,7-bis (6-methoxy-2-formylphenyl)-1,7-dioxaheptane (I) with 2,2′-(ethylenedioxy) bis(ethylamine) in methanol, the IR spectrum of ligand (III) shows a $\nu(\mathrm{CH{=}N})_{\mathrm{str}}$ peak at 1650 cm^{-1} and the absence of a $\nu(\mathrm{C{=}O})$ peak at around 1690 cm^{-1} for (I) is indicative of Schiff base condensation (Salih and Hamid, 2008). The mass spectra show a molecular peak at m/z = 1036 for (III) and m/z = 406 for (I), which are confirmed by the formation of macrocyclic Schiff base (III), the NMR

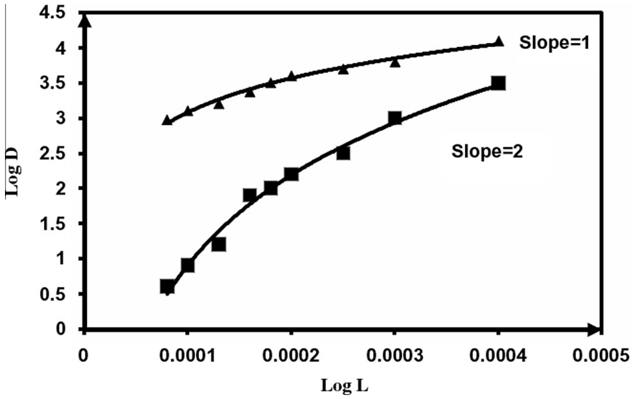


Figure 2 Plots of log D versus log L for the extraction of Ag-picrate (■) and Cu-picrate (▲).

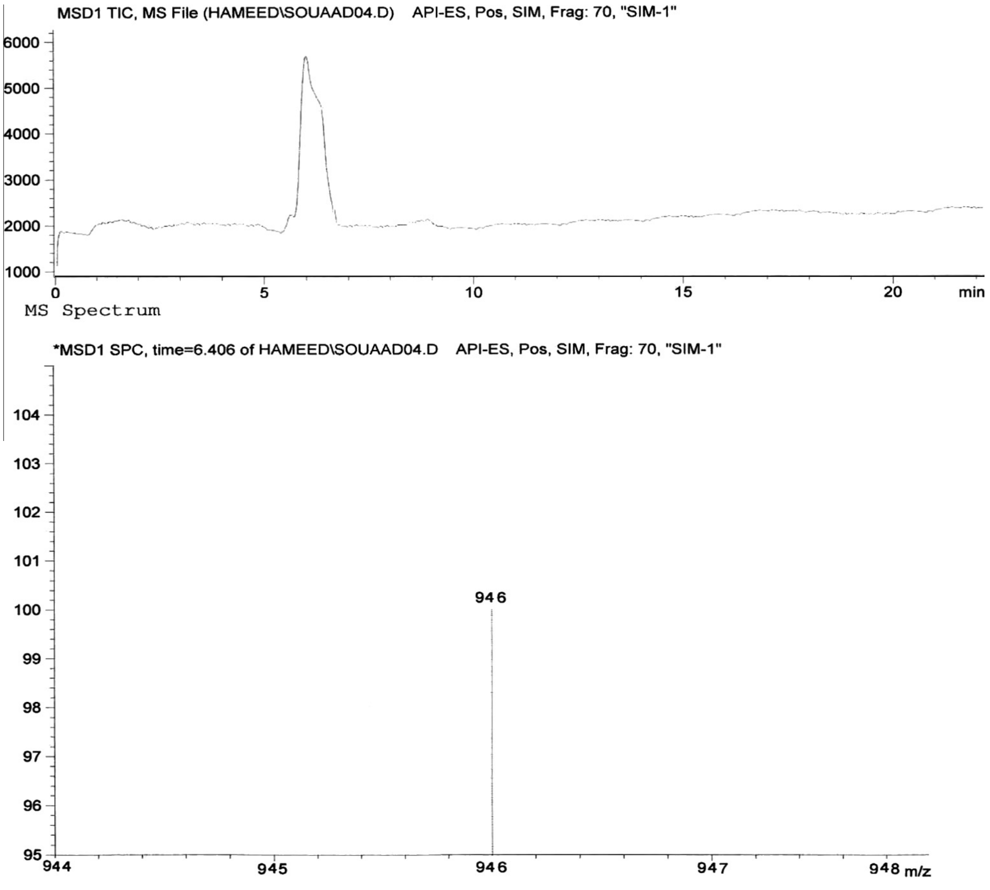


Figure 3 Chromotgram (LC–MS) of ligand (II).

spectrum of ligand (III) exhibits aromatic protons at 7.10–7.42 ppm and imine protons at 8.23 ppm, but no signals corresponding to the formyl or amine protons are presented.

4.2. Extraction of metal picrates

Table 1 shows the extractability of Ag^+, Cu^{2+} and Ni^{2+} picrates from the aqueous phase into an organic phase by the macrocyclic Schiff bases (II) and (III). It is clear that the extractability results of the macrocyclic Schiff bases are different for both of the organic solvents. When dichloromethane was used as an organic solvent macrocyclic (II) extracted Ag^+ ion in 72.2% but the other metal ions are not extracted effectively. Macrocyclic (III) extracted Ag^+ ion in 84.3% for the same solvent. It is interesting that the percentage of the extraction of the metal ions with macrocyclic (III) is higher than that of macrocyclic (II) for both of the solvents. These results suggest that the phenyl group is the efficient group in the extraction and an increase in the number of oxygen donors increases the percentage of the extraction of the metal ions. It can be seen from Table 1 that the solvent has an important effect upon the cation extractability. These results may depend on dielectric constants, the solvents. The dielectric constants of dichloromethane and chloroform are 9.1 and 4.8, respectively. Dichloromethane having high dielectric constants is favored for the extraction of all the metal ions; there are similar results in literature (Ziyadonogullari et al., 2001). On the other hand, the better solvation of the complexes by dichloromethane may

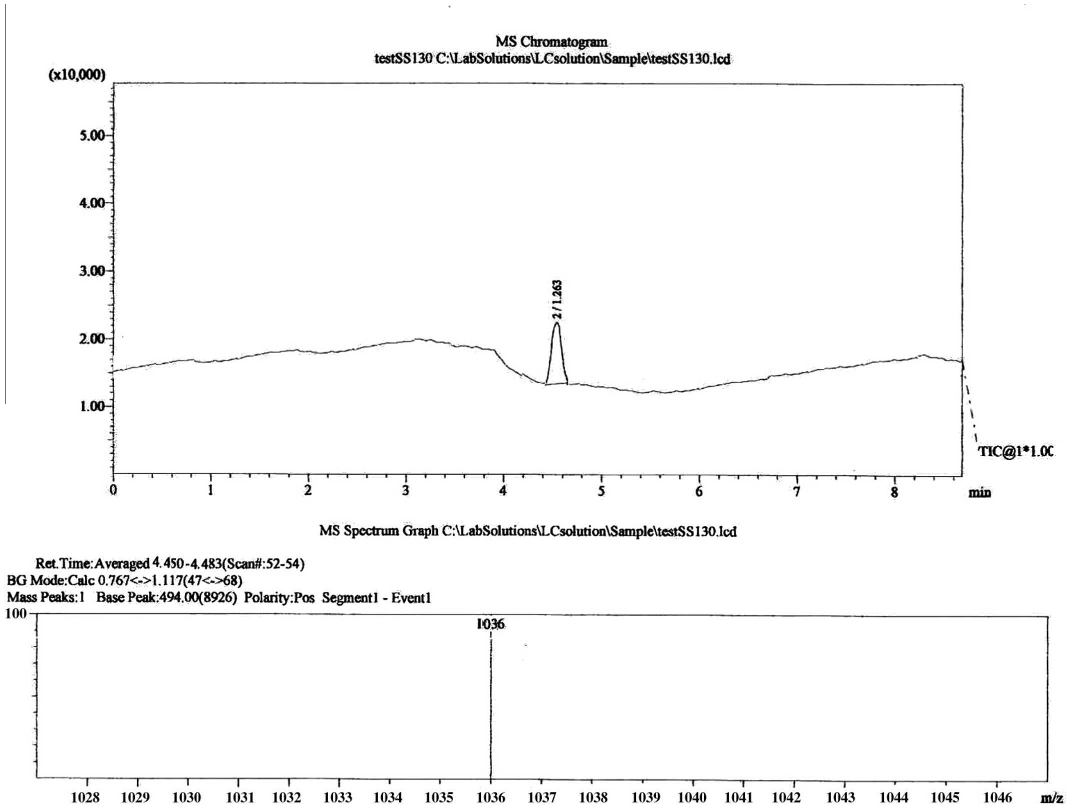


Figure 4 Chromotgram (LC–MS) of ligand (III).

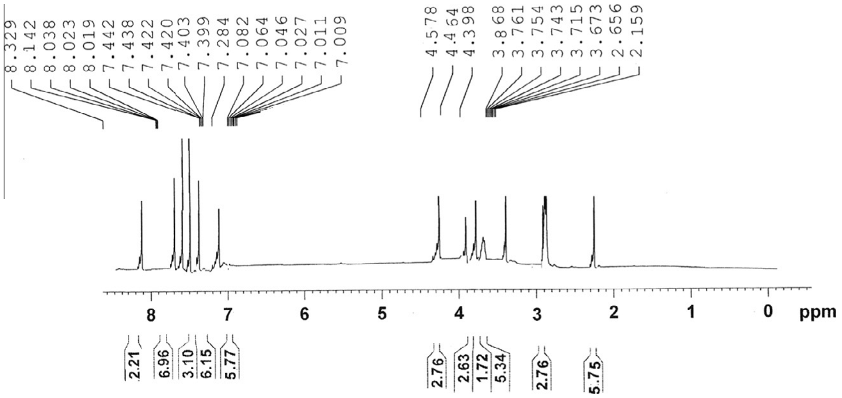


Figure 5 Chromotgram (^1H NMR) of ligand (II).

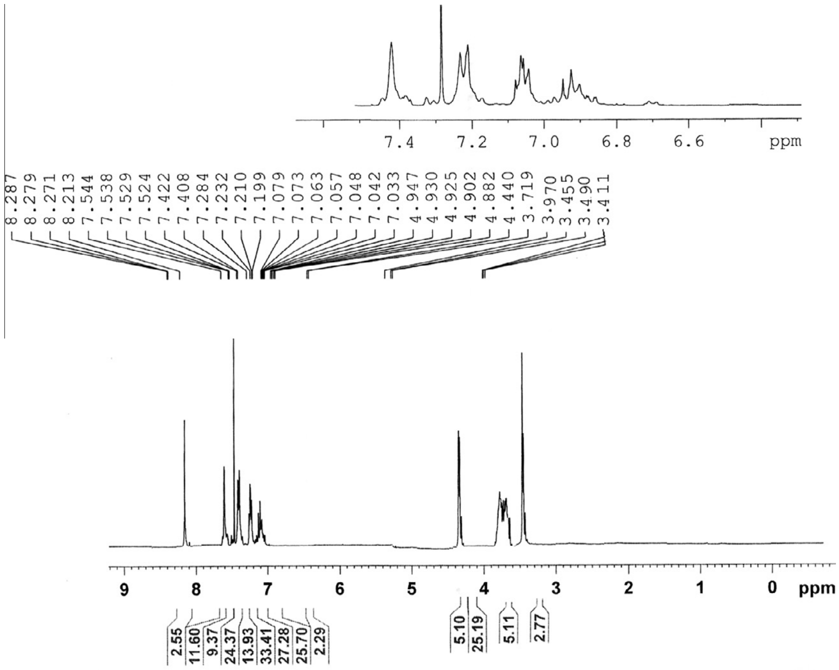


Figure 6 Chromotgram (^{1}H NMR) of ligand (III).

Table 3 The relationship between the composition extraction constant and ionic diameter for the cation-macrocyclic Schiff base (III) complex.

Metal ion	Complex composition (L:M)	Ionic diameter (A°)
Ag^+	1:01	2.51
Cu^{2+}	1:02	1.64

be a valuable reason for the better extraction. From the extraction data shown in Table 1 it is clear that the ligands which have N_6O_4, N_4O_8 donor sets show that both of the cation-cavity size and the type of binding sites in the ring contribute to the ability of Ag^+ ion binding.

Table 2 shows the selectivity of silver picrate over the other metal picrate for the macrocyclic Schiff bases (II) and (III). The selectivity is indicated as D_{Ag+}/D_m^{n+}. D_{Ag+} and D_m^{n+} denotes the distribution ratio of Ag^+ ion and M^{n+} ion, respectively. The macrocyclic Schiff bases (II) and (III) indicated high selective extraction of Ag^+ ion over the Cu^{2+} and Ni^{2+} ions with 9.9 and 14.4, respectively. The selectivity results for to dichloromethane are higher than those for chloroform (Fig. 1).

Fig. 2 shows the extraction into dichloromethane at a different concentration of ligand from 1×10^{-5} M to 1.5×10^{-4} M.

A liner relationship between log *D* versus log *L* is observed. (Figs. 3–6).

The slope of equal to 1 suggesting the ligand (III) forms a (1:1) (L:M) for Cu^{2+} complex with ligand (III), The slope of equal to 2 suggesting the ligand (III) forms a (1:2) (L:M) for Ag^+ complexe with ligand (III).

Table 3 shows the relationship between the complex composition and ionic diameter for the macrocyclic-cation. Schiff base (III) gives the (1:1) (L:M) complex for Cu^{2+} and (1:2) (L:M) complex for Ag^+.

5. Conclusion

The novel macrocyclic Schiff bases (II) and (III) have a good extraction abillity of Ag^+ ion from the aqueous phase to the dichloromethane phase.

But it was observed to have a high extraction of Ag^+ ion with the macrocyclic Schiff base (III) which has N_4O_8 donor sets than that of macrocyclic (II) which has N_6O_4donor sets.

It was found that macrocyclics that have N_6O_4, N_4O_8 donor sets extracted Ag^+ compared with the other transition metal cations (Cu^{2+} and Ni^{2+})as selective.

The composition of the extracted Ag^+ complexes was (1:2) (L:M) and Cu^{2+} complex was (1:1) (L:M) for of ligand (III).

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