SYNTHESIS, SPECTRAL CHARACTERIZATION AND THERMAL BEHAVIOUR OF NEW METAL(II) COMPLEXES WITH SCHIFF BASE DERIVED FROM AMOXICILLIN

AURORA REISS*, ADRIANA SAMIDE, GEORGETA CIOBANU, IRINA DĂBULEANU

Department of Chemistry, Faculty of Mathematics and Natural Sciences, University of Craiova, 107i Calea București, 200478 Craiova, Romania,

ABSTRACT

Metal complexes of Schiff base derived from different antibiotics are widely employed as biological active materials, especially as antibacterial agents. Two new metal (II) complexes with the Schiff, base (HL) derived from amoxicillin and salicylaldehyde were synthesized and investigated using elemental analysis, spectroscopic techniques (IR and UV-Vis), conductometric and magnetic measurements. The IR spectra illustrated a bidentate ligand which coordinates through phenolic oxygen atom and imino nitrogen atom from azomethine bond. UV-Vis spectrophotometry showed the characteristic adsorption bands corresponding to an octahedral geometry for both metal complexes. The general formula established from experimental data was found to be $[ML_2(H_2O)_2]$ ($M=Co(II)$ and $Ni(II)$). This composition was further confirmed by thermal analysis and their thermal stability in nitrogen atmosphere was investigated. Antibacterial study showed that the efficiency of metal complexes is higher than the one found for the free Schiff base ligand.

Key words: Schiff base, amoxicillin, metal complexes, thermal analysis, antibacterial study

INTRODUCTION

Complexes with Schiff bases as ligands attract many researchers because of their wide application in medicinal chemistry, food industry, analytical chemistry, dye industry, catalysis, etc. and also for their simple methods to be prepared. Many studies reported several metal complexes of Schiff base derived from different antibiotics and their biological activity¹⁻⁸. In all these cases it was found that metal complexes showed increased antimicrobial activity than their parent Schiff bases.

Amoxicillin(2*S*,5*R*,6*R*)-6-[[[(2*R*)-2-amino-2-(4-hydroxyphenyl)-acetyl]amino]-3,3-dimethyl-7-oxo-4-thia-1-azabicyclo[3.2.0]heptane-24-carboxylic acid) is a member of penicillin' s group which are a very important class of β -lactamic antibiotics used to treat bacterial infections caused by microorganisms. The mechanism that makes bacteria resistant to β -lactams is due to the synthesis of β -lactamase enzymes which break the β -lactam ring and the antibiotic cannot bind to peptidoglycan layer⁹. Amoxicillin is sometimes combined with clavulanic acid, a β -lactamase inhibitor, to increase the spectrum of action against Gram-negative organisms, and to overcome bacterial antibiotic resistance mediated through β -lactamase production. From a coordination chemistry perspective it has been demonstrated that all the β -lactamic antibiotics possess a number of potential donor sites. Atoms involved in coordination and the structure of these complexes depend on several factors including reaction medium, pH, temperature, solvents, etc. Iqbal M. et al.¹⁰ reported Cu(II) and Zn(II) complexes with Schiff base derived from amoxicillin and salicylaldehyde which were characterized by conventional methods such as microanalytical, magnetic and spectroscopic techniques associated with thermal analysis. Joshi S. et al.¹¹ synthesized Co(II), Zn(II), Ni(II) and Mn(II) complexes with Schiff base derived from amoxicillin with two aldehydes - cinnamaldehyde and p-chlorobenzaldehyde - having improved antibacterial activity than the one that was found for free Schiff bases. Taghreed H.Al-Noor et al.¹² synthesized mixed ligand complexes of Fe(II),Co(II),Ni(II),Cu(II), and Zn(II) containing Schiff base derived from amoxicillin and 4-dimethylaminobenzaldehyde with nicotinamide in 1:1:2 ratio. These synthesized complexes present relevant microbiological activity in comparison with the Schiff base.

As a part of our continuing efforts to synthesize and characterize Schiff base metal complexes¹³⁻¹⁵, in this paper we present the synthesis, infrared and UV-Vis spectra, thermal analysis and antibacterial study of new Co(II) and Ni(II) complexes with Schiff base derived from amoxicillin and salicylaldehyde (Figure 1.).

The paper was structured as follows: (i) introduction relates the state of art of topic; (ii) in experimental procedure, the methods of synthesis and the characterization techniques were described; (iii) the results were adequate discussed according to the experimental data obtained under our laboratory conditions and taking into consideration the known literature data; the results of antibacterial tests on *Escherichia coli*, *Staphylococcus aureus* and *Pseudomonas aeruginosa* were also commented based on detailed investigation which allowed the pertinent conclusions.

Figure 1. Structure of the Schiff base ligand (HL).

EXPERIMENTAL

Materials and Methods

Salicylaldehyde (Aldrich, Germany) and amoxicillin trihydrate (Iasi, Romania) were used to prepare the Schiff base that was mixed with (each) Co(II) and Ni(II) chloride (Merk, Germany) in order to synthesize their complexes. All reagents and chemicals were of analytical grade, commercially available, and were used without further purification.

The elemental analysis was performed with a Carlo Erba EA1108 elemental analyser. The metal content of the complexes was determined by atomic absorption technique using Varian-AA775 spectrophotometer. The IR spectra were recorded on a Perkin Elmer 157 instrument in anhydrous KBr pellets in the range 300-4200 cm^{-1} . The UV-Vis spectra were carried out at room temperature in 10^{-3} N,N-dimethylformamide (DMF) with the Unicam UV2-300 spectrometer. The molar conductivities were determined by using OK-102 conductometer. The magnetic susceptibility measurement was made on a Faraday balance, at room temperature, magnetic moments were thus calculated. The melting points were determined by using Sanyo Gallenkamp apparatus.

The thermal analysis was performed in nitrogen atmosphere, using a Diamond analyzer from Perkin-Elmer with Pyris software. The sample of 3.0 mg (for each) was heated in platinum crucibles in the temperature range from RT (room temperature) to 1273 K, with a heating rate of 10 K min^{-1} . The thermal behaviour of both complexes was discussed according to TG/DTG/DSC recorded curves.

Synthesis of the Schiff base ligand (HL)

Firstly, the Schiff base was prepared from 25 mL methanol containing 0.419 g (1mM) amoxicillin and 15 mL methanol where has been dissolved in advance 0.61 g (1mM) salicylaldehyde. In order to obtain the pH value between 7 and 8, 1.0 M NaOH solution was added and the mixture was refluxed a time of 2 hours. The volume of the solution was reduced to one half by evaporation when an orange precipitate was formed. It was filtered, washed with methanol and dried *in vacuo* at room temperature under anhydrous $CaCl_2$. Recrystallization from a mixture of ethanol - water (50:50) gave the Schiff base; m.p. 192-194°C. Analytical data: Schiff base: Found: C, 58.65; H, 4.87; N, 8.87 % Calcd. for $C_{23}H_{23}O_6N_3S_1$: C, 58.84; H, 4.90; N, 8.95 % ; Yield: 81%.

Synthesis of the metal complexes

The metal complexes were prepared in the same manner by mixing 2.0 mM Schiff base with 25 mL methanol containing $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ (1.0 mM) or $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$ (1.0 mM). The mixtures pH value was adjusted to 7-8 by adding 1.0 M NaOH solution and then they were refluxed a time of 2 hours. Finally, the volume of solutions was reduced to one half by evaporation, and in both cases, an occurrence of colored precipitate was observed this being assigned to Co(II) complex or Ni(II) complex respectively. It was filtered, washed with methanol and dried *in vacuum*. Recrystallization from hot methanol gave the metal complexes. Analytical data: $\text{CoL}_2(\text{H}_2\text{O})_2$: color: reddish brown; m.p. 196-198°C Found: C, 53.51; H, 4.58; N, 8.12; Co, 5.67 %; Calcd. for $\text{CoC}_{46}\text{H}_{48}\text{O}_{14}\text{N}_6\text{S}_2$: C, 53.54; H, 4.65; N, 8.14; Co, 5.71 %; Yield: 76%; $\text{NiL}_2(\text{H}_2\text{O})_2$: color: brown; m.p. 200-202°C Found: C, 53.53; H, 4.62; N, 8.04; Ni, 5.65 %; Calcd. for $\text{NiC}_{46}\text{H}_{48}\text{O}_{14}\text{N}_6\text{S}_2$: C, 53.55; H, 4.65; N, 8.14; Ni, 5.69 %; Yield: 85%.

Antimicrobial studies

The newly synthesized metal complexes and the free Schiff base ligand were screened for antibacterial activity against pathogenic bacterial species *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa* and comparisons were made.

The paper disk diffusion method was adopted for the determination of antibacterial activity¹⁶. This method is simple and is routinely used in hospital laboratories. The ligand/complex (30 μg) in DMF (0.01 mL) was placed on a paper disk with 3 mm in diameter with the help of a micropipette. The disks were left in an incubator for 48 h at 37°C and then were applied to the bacteria grown on agar plates. For the preparation of agar plates for bacterial species, Mueller-Hinton agar with 2% of glucose (50 g), obtained from Merck, was suspended in freshly distilled water (1 L). It was allowed to soak for 15 min and then was boiled in a water bath until the agar was completely dissolved. The mixture was autoclaved for 15 min at 120 °C, poured into sterilized petri dishes, and then stored at 40 °C for inoculation. Inoculation was performed with a platinum wire loop that was made red hot in a flame, cooled, and then used for the application of bacterial strains. Each paper disk was placed on an already inoculated agar plate which was then incubated at 37 °C for 24 h. Activity was determined by measuring the diameter of zones showing complete inhibition (mm).

RESULTS AND DISCUSSION

The Schiff base ligand was prepared by refluxing the appropriate amount of amoxicillin with salicylaldehyde in methanol and its structure was established by IR spectrum and microanalytical data (Figure 1). The metal complexes of Schiff base ligand were prepared by the stoichiometric reaction of the corresponding metal(II) chloride with the ligand in a molar ratio of 1 : 2. The complexes were obtained as air-stable amorphous solids which are insoluble in water, partially soluble in methanol and ethanol, totally soluble in *N,N*-dimethylformamide (DMF) and dimethyl sulfoxide (DMSO). The molar conductivities of the complexes measured in 10^{-3} M DMF, at room temperature have low values of 13 - 18 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$ indicating their non-electrolyte nature¹⁷. The elemental analysis above mentioned for both complexes leads to the following empirical molecular formula: $\text{ML}_2(\text{H}_2\text{O})_2$, where M = Co(II) and Ni(II) and L= deprotonated Schiff base ligand.

Infrared spectra

IR spectra for amoxicillin trihydrate, Schiff base ligand and metal complexes were recorded in wavenumber range between 300 - 4200 cm^{-1} . IR spectrum of amoxicillin trihydrate showed absorption bands at 3442, 3200, 1775 and 1688 cm^{-1} corresponding to $\nu(\text{OH})$, $\nu(\text{NH}_2)$, $\nu(\text{C=O})$ -lactam and $\nu(\text{C=O})$ amide stretching frequencies, respectively. A comparison of the IR spectra of amoxicillin trihydrate and Schiff base ligand provides proof of the formation of the Schiff base between amoxicillin and salicylaldehyde. The principal band responsible for this is the new absorption band at 1613 cm^{-1} attributed to $\nu(\text{C=N})$ stretching vibration; the bands attributed to $\nu(\text{C=O})$ -lactam and $\nu(\text{C=O})$ amide are slightly shifted to 1770 and 1685 cm^{-1} , respectively.

By comparing the IR spectra of the metal complexes with those of the free Schiff base it can be obtained the information about the bonding of the ligand to metal ions; as an example, in Figure 2 are shown IR spectra for Schiff base ligand and Co(II) complex. The most important absorption bands and their assignments are listed in Table 1.

The IR spectra of the complexes contains several absorption bands from the Schiff base and also, new absorption bands, these being attributed to the coordination of the ligand to metal ions through nitrogen atom from azomethine bond and oxygen atom from phenolic group.

Figure 2. IR spectra for Schiff base and $[\text{CoL}_2(\text{H}_2\text{O})_2]$.

The main bands in the IR spectrum of the free Schiff base are at 3342, 1613 and 1252 cm^{-1} attributed to $\nu(\text{OH})$, $\nu(\text{C=N})$ azomethine and $\nu(\text{CO})$ phenolic, respectively. The band at 3342 cm^{-1} in the ligand spectrum disappears from the complexes as an indicative of phenolic group deprotonation. Instead, the band at 1252 cm^{-1} assigned to $\nu(\text{CO})$ phenolic vibration is shifted by 17 cm^{-1} in comparison with the ligand, as a result of both deprotonation and coordination of phenolic oxygen. These shifts indicate the participation of the oxygen atom of the deprotonated hydroxyl group which is situated in a favorable position (orto) towards the azomethine group. The spectra of metal complexes exhibited a broad band around 3400 cm^{-1} , which is assigned to water molecules, $\nu(\text{H}_2\text{O})$, associated with the complexes. Coordinated water molecules exhibited $\rho r(\text{H}_2\text{O})$ rocking near 834, 863 cm^{-1} and $\rho w(\text{H}_2\text{O})$ wagging near 567, 541 cm^{-1} ¹⁸. IR spectra of the ligand presented a band at 1613 cm^{-1} attributed to $\nu(\text{HC=N})$ azomethine group, which is shifted to a higher value in both complexes at 1624 and 1630 cm^{-1} suggesting that the ligand is coordinated to the metal ion through nitrogen atom from azomethine group. The new absorption bands $\nu(\text{MN})$ and $\nu(\text{MO})$ observed in spectra of complexes at 530, 534 cm^{-1} and 464, 454 cm^{-1} , respectively (see inserted spectrum in Figure 2) shows the coordination of the ligand through nitrogen and oxygen¹⁹.

Consequently, the IR spectra illustrate a bidentate ligand that coordinates through phenolic oxygen atom and imino nitrogen atom from azomethine bond. The coordination sphere of the metal is completed by the water molecules.

UV-Vis spectra and magnetic measurements

In order to obtain information regarding the coordination geometry of the complexes, the electronic spectra were determined at room temperature in DMF and the data obtained were correlated with magnetic moment values and ligand field parameters: splitting energy (10Dq), interelectronic repulsion parameter (B) and nephelauxetic ratio (β) (Table 2). The electronic spectra of the ligand presents two absorption bands at 40260 and 32450 cm^{-1} , respectively, attributed to $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$, respectively, determined by the C=O and C=N groups. These absorption bands also appear in the electronic spectra of the complexes but they are shifted to lower values, which proves the coordination of the ligand to the central metallic ions²⁰.

The electronic spectra of the Co(II) complex displays two bands at 10150 cm^{-1} (ν_1) and 22125 cm^{-1} (ν_3), which are assigned to ${}^4\text{T}_{1g}(\text{F}) \rightarrow {}^4\text{T}_{2g}(\text{F})(\nu_1)$; ${}^4\text{T}_{1g}(\text{F}) \rightarrow {}^4\text{T}_{1g}(\text{P})(\nu_3)$ transitions, respectively. These are the characteristic bands of high spin octahedral Co(II) complexes²⁰. The ligand field parameters (Dq, B, β) are calculated using E. Koning equations²¹, when only ν_3 and ν_1 bands are observed in the electronic spectra and the values are well within the range reported for the octahedral complexes²². The value of the magnetic moment was 4.83 BM for Co(II) complex which suggests three unpaired electrons in an octahedral environment²³.

The electronic spectrum of Ni(II) complex presents two d-d absorption bands at 10720 and 16340 cm^{-1} in an octahedral environment corresponding to ${}^3\text{A}_{2g} \rightarrow {}^3\text{T}_{2g}(\text{F})(\nu_1)$ and ${}^3\text{A}_{2g} \rightarrow {}^3\text{T}_{1g}(\text{F})(\nu_2)$, transitions²⁰. For d^8 ions in an octahedral environment, the energy of ν_1 corresponds to 10Dq and the value of Dq is obtained from it²¹. The values obtained for Dq, B, β are in agreement with the experimental ones for Ni(II) octahedral complexes²². The magnetic moment value of Ni(II) complex is 3.12 BM indicating the presence of two unpaired electrons on Ni(II) ion and suggesting that this complex has an octahedral geometry^{24,25}.

Table 1. Relevant IR data of the Schiff base (L) and its metal complexes (cm^{-1}).

Compound	$\nu(\text{H}_2\text{O})$ coord.	$\nu(\text{OH})$	$\nu(\text{C}=\text{O})$ carbox.	$\nu(\text{HC}=\text{N})$ azm.	$\nu(\text{CO})$ phenolic	$\delta_r(\text{H}_2\text{O})$ $\delta_w(\text{H}_2\text{O})$ coord.	$\nu(\text{MO})$ $\nu(\text{MN})$
Schiff base (HL)	-	3342 (1)	1719 (2)	1613 (3)	1252 (4)	-	-
$[\text{CoL}_2(\text{H}_2\text{O})_2]$	3395 (1')	-	1713 (2')	1624 (3')	1235 (4')	834 (5') 567 (6')	530 (7') 464 (8')
$[\text{NiL}_2(\text{H}_2\text{O})_2]$	3397	-	1713	1630	1235	843 541	534 454

* Numbers (1) - (4) and (1') - (8') correspond to the peaks from Figure 1.

Table 2. Absorption maxima from electronic spectra and crystal field parameters for Schiff base (L) and its complexes.

Compound	Absorption maxima(cm^{-1})	Assignments	Crystal field parameters		
			10Dq(cm^{-1})	B(cm^{-1})	β
L	40260 32450	$\pi \rightarrow \pi^*$ $n \rightarrow \pi^*$	-	-	-
$[\text{CoL}_2(\text{H}_2\text{O})_2]$	38360 29570 22125 (ν_3) 10150 (ν_1)	$\pi \rightarrow \pi^*$ $n \rightarrow \pi^*$ ${}^4\text{T}_{1g}(\text{F}) \rightarrow {}^4\text{T}_{1g}(\text{P})$ ${}^4\text{T}_{1g} \rightarrow {}^4\text{T}_{2g}(\text{F})$	1145	885	0.911
$[\text{NiL}_2(\text{H}_2\text{O})_2]$	37360 29870 16340 (ν_2) 10720 (ν_1)	$\pi \rightarrow \pi^*$ $n \rightarrow \pi^*$ ${}^3\text{A}_{2g} \rightarrow {}^3\text{T}_{1g}(\text{F})$ ${}^3\text{A}_{2g} \rightarrow {}^3\text{T}_{2g}(\text{F})$	1072	646	0.627

Thermal analysis

The thermal analysis of both complexes was detailed as TG/DTG/DSC curves which are illustrated in Figure 3.

Figure 3. Thermoanalytical curves recorded for Co(II) and Ni(II) complexes: a - TG curve of Co(II) complex; b - DTG/DSC curves of Co(II) complex; c - TG curve of Ni(II) complex; d - DTG/DSC curves of Ni(II) complex.

It can be observed that, at low temperature up to 200 °C, the events can be assigned to; (i) the elimination of some adsorbed gases and/or evaporation of the volatiles which were resulted during complexes synthesis; (ii) the removing of ~2.0 moles of coordinated water, that is in good agreement with the expected mass loss (Figures 3a and 3c). The mass loss obtained for volatiles may be explained by the fact that the complexes were superficially dried in warm air at temperature below 40 °C to prevent alteration of complexes composition by accidentally loss of water. The endothermic effects on DSC curves can be observed as the shoulders with the maxima shifted to higher temperature values of 207 °C and 210 °C, respectively (Figures 3b and 3d) indicating an overlapping with other processes, most probable with the evaporation of physically adsorbed Schiff base on the particles of complexes. In temperature range between 180-

440 °C the decomposition of both complexes takes place with the highest mass loss (Figures 3a and 3c), with the rupture of the coordination bonds between the metal and ligand or with the rupture of bonds from inside the ligand followed by the elimination of several by-products with the exothermic effects observed on DSC curves, at 374 °C and 371 °C, respectively. Moreover, in this temperature range parallel courses could occur of Schiff base elimination and /or loss of one or the other Schiff base component. This would explain the appearance of peaks observed on the DTG curves at 240 °C and 242 °C, respectively. Consequently, up to 440 °C a similar process of decomposition occurs for the both complexes, thus the decomposition events do not involve other outstanding remarks than those listed in Table 3.

Table 3. Characteristics of the thermodegradation steps of Co(II) and Ni(II) complexes.

Complex	Step	Temperature range/°C	Thermal effect	Maximum/°C		Mass loss/%	Associated process
				DTG	DSC		
CoL ₂ (H ₂ O) ₂	1	RT-85	Endo	52	52	4.5	loss of adsorbed gases and/or adsorbed volatiles resulted from synthesis
	2	85-180	Endo	shifted to 207 on DSC curve		3.8	loss of coordinated water
	3	180-440	Exo	240	374	40.8	Schiff base decomposition
	4	440-550	Exo	477	477	14.3	decomposition of some by-products
	5	550-665	Exo	638	638	12.8	decomposition of some by-products
	6	665-1000	-	-		2.1	gradual loss of mass due to elimination of some gases, such as O ₂
	residue					21.7	65.6 % C; 16.6 % CoO; 17.8 % Co ₃ O ₄
NiL ₂ (H ₂ O) ₂	1	RT-85	Endo	52	52	5.8	loss of adsorbed gases and/or adsorbed volatiles resulted from synthesis
	2	85-180	Endo	shifted to 210 on DSC curve		3.9	loss of coordinated water
	3	180-440	Exo	242	371	36.3	Schiff base decomposition
	4	440-606	Exo	584.5	584.5	20.9	decomposition of some by-products
	5	606-1000	-	-		6.8	gradual loss of mass due to the elimination of some gases, such as: CO, CO ₂
	residue					26.3	77.2 % C; 17.8 % NiO; 5.0 % Ni

At higher temperature than 440 °C the Co(II) complex decomposed in two steps (Figure 3a), followed by the exothermic effects with the temperature maxima nuanced on both DTG and DSC curves at 477 °C and 638 °C, respectively (Figure 3b). After 665 °C, gradual mass loss with the small value of 2.1% takes place, and remaining a final residue of 21.7%, suggesting that this could be composed of a mixture containing carbon and metal oxides, the latter being in equilibrium state, as shown in reaction I.

In the same temperature range the decomposition of Ni(II) complex takes place through a single step (Fig. 3c) with an exothermic effect at 584.5 °C (Figure 3d), being in good agreement with the known literature data which showed that the nickel complexes is faster decomposed under high temperature than similar complexes of cobalt²⁶. After 606 °C the mass loss has a higher value than that was recorded for Co(II) complex because in presence of carbon or CO the Ni oxide reduces to metal^{27,28} as reactions II and III show, final residue being of 26.3%; this is consists of a mixture containing C, Ni and NiO. Similar events were reported for Cu(II) and Zn(II) complexes of Schiff bases obtained by condensation of amoxicillin and salicylaldehyde¹⁰. Other studies showed that amoxicillin was thermally decomposed at several stages with a total weight loss of 51.06%, leaving a residual mass at 350 °C of 48.94%. Also, distinctive decomposition steps of complexes derived from salicylaldehyde²⁹ were presented. Moreover, similar assumptions were reported for residue composition related to thermal decomposition of other transition metal complexes under nitrogen atmosphere³⁰.

M. Lalia-Kantouri³¹ showed that the by-products formed after the main degradation step (in our study after 400 °C) are not stable and further heating of all the complexes at 700 °C leads to a residue consisting in a carbonaceous metal oxide³⁰. The details for each studied compound are given in Table 3. Knowing that CoO converts to Co₃O₄ (CoO · Co₂O₃) if it is heated to around

600-700 °C and that above 900 °C, Co₃O₄ decomposes to CoO^{29,30}, the following equilibrium describes these reactions:

Based on this equilibrium and taking into consideration that Co(II) complex contains 5.7% Co which remains in final residue of 21.7%, an algorithm to calculate the residue composition was applied. As shown in Scheme 1, "x" is attributed to moles of Co₃O₄ and "y" represents the carbon amount from final residue, at 1000 °C. By applying the corresponding molecular mass to CoO and Co₃O₄, the associated equations were deduced taking into consideration that the ratio of oxides is 3/1, as shown in reaction I.

Scheme 1. The applied algorithm to calculate the residue composition for [Co(II) complex] thermal decomposition, up to 900 °C.

In order to estimate the residue composition of Ni(II) complex the following reactions II and III are used. Based on the observation that in temperature range between 900-1000°C, the mass loss is obviously greater, reaching a value of 3.5% (Figure 3c) due to the CO₂ elimination in the same amount, it can be observed that an equivalent number of moles (0.0795) is attributed to NiO reduced at metallic Ni.

The corresponding molecular mass and the Ni proportion from NiO were used to determine the composition of residue obtained at Ni(II) complex decomposition (26.3%) at 1000 °C (Scheme 2).

Scheme 2. The applied algorithm to calculate the residue composition for [Ni(II) complex] thermal decomposition, at 1000 °C.

Thermal degradation data of both complexes confirm the presence and the nature of water molecules and the stoichiometry of the studied metal complexes. The molecules of coordinated water released with an endothermic effect and the degradation process followed with an exothermic effect.

Based on analytical data, IR and UV-Vis spectra, and thermal analysis the proposed structure of the complexes is shown in Figure 4.

Figure 4. Structure of metal complexes where M = Co(II) and Ni(II)

Antibacterial study

The Schiff base and its complexes were tested for in vitro antibacterial activity using the diffusion method against *E. coli*, *S. aureus*, *P. aeruginosa*. The antibacterial activity was estimated on the basis of the size of inhibition zone formed around the paper disks on the seeded agar plates. Growth inhibition was compared with known antibiotics viz. ciprofloxacin. The results are presented in figure 5.

The Schiff base and the complexes exhibited varying degrees of inhibitory effects on the growth of the tested bacterial species. As observed, the free Schiff base is moderately active against the bacterial species while the antibacterial activity of the Schiff base became more pronounced when it is coordinated to the metal ions. Referring to complexes, we note that the Co(II) complex is more active as compared with Ni(II) complex. In conclusion, the biological activity of the complexes follow the order: Co(II) > Ni(II) > Schiff base ligand.

Figure 5. Biological activity of the Schiff base ligand and its complexes

Furthermore, the data show that *E. coli* was inhibited to a greater degree by the Co(II) complex. The complexes prepared with Schiff base derived from amoxicillin and salicylaldehyde could reasonably be used for the treatment of some common diseases caused by *E. coli*.

An antibacterial activity of metal complexes better than the one of the Schiff base ligand can be explained on the basis of Overtone's and Tweedy's concepts^{32,33}. According to Overtone's concept of cell permeability, the lipid membrane that surrounds the cell favours only the passage of lipid soluble materials, therefore liposolubility is considered to be an important factor that controls the antibacterial activity. Drawing on chelation theory, Tweedy's concept explains the increase of lipophilic character of the metal chelate. Upon chelation, the positive charge of the metal ion is partially shared with the donor atom present on the ligand and a π -electron delocalization over the whole chelate ring takes place. In this way, the lipophilic character of the metal chelate increases and favours its permeation through the lipid layers of the bacterial membranes and blocks the metal binding sites in the microorganism.

CONCLUSIONS

The new Co(II) and Ni(II) complexes with the Schiff base derived from amoxicillin and salicylaldehyde were synthesized and characterised. The data collected from IR spectra showed that the Schiff base behaves as a bidentate ligand coordinated in both complexes. Electronic spectra and magnetic measurements indicated an octahedral stereochemistry for the metal complexes. The thermal analysis presented the thermal degradation data of both complexes showing that the molecules of coordinated water were released with an endothermic effect and the degradation process was followed by an exothermic effect. Bacteriological studies were carried out against three species. The results showed increase in antimicrobial activity of metal complexes as compared with uncomplexed ligand.

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