Int. J. Electrochem. Sci., 4 (**2009**) 717 - 729

International Journal of ELECTROCHEMICAL SCIENCE
www.electrochemsci.org

Electrochemical Properties of some Transition Metal Complexes: Synthesis, Characterization and *In-vitro* antimicrobial studies of Co(II), Ni(II), Cu(II), Mn(II) and Fe(III) Complexes

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Received: 15 February 2009 / *Accepted:* 4 April 2009 / *Published:* 4 May 2009

A series of first complexes of Co(II), Ni(II), Cu(II), Mn(II) and Fe(III) have been synthesized with Schiff base derived from isatin monohydrazone and fluvastatin. The complexes have been characterized in the light of elemental analyses, spectral (IR, Uv-Vis., FAB-mass and ESR) and magnetic studies. The elemental analyses of the complexes confine to the stoichiometry of the type $ML_2.2Cl$ [M=Co(II), Ni(II), Cu(II) and Mn(II)] and $[FeL_2.2Cl]Cl$. The redox properties of the complexes were extensively investigated by electrochemical method using cyclic voltammetry (CV). The Co(II) and Cu(II) complexes exhibited quasi-reversible single electron transfer process where as Mn(II) and Fe(III) complexes shown two redox peaks of quasi-reversible one electron transfer process. The Schiff bases and their complexes have been screened for their *in-vitro* antibacterial (*Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa* and *Bacillus subtilis*) and antifungal (*Aspergillus niger and Pencillium Chrysogenum*) activities by minimum inhibitory concentration (MIC) method.

Keywords: Electrochemistry; Isatin; Spectral characterization; Transition metals

1. INTRODUCTION

Isatin, an endogenous indole and its derivatives have been shown to exhibit a wide range of biological activities [1–5]. Isatin-thiosemicarbazone copper(II) complexes related to the antiviral drug, methisazone were prepared electrochemically or by usual condensation methods, being characterized by different spectroscopic techniques [6]. Also the biological significance of fluvastatin, an indole derivative, is well established [7]. A significant rising interest in the design of metal compounds as drugs and diagnostic agents is currently observed in the area of scientific inquiry appropriately termed medicinal inorganic chemistry [8]. Metal complexes with Schiff bases of isatin derivatives exhibited remarkable biological activity [9-11]. In recent years the electrochemical techniques have led to the advancement in the field of analysis because of their sensitivity, low cost and relatively short analysis time when compared with other techniques. Additional application of electroanalytical techniques includes the determination of reaction mechanisms. Redox properties of a drug can give insights into its metabolic fate or pharmaceutical activity [12-14].

Although much attention has been directed to study the metal complexes of the Schiff base ligands derived from isatin [15, 16], no investigations have appeared in the literature to describe the metal complexes of the Schiff base derived from isatin monohydrazone and fluvastatin. And also, to the best of our knowledge this is the first report on the metal complexes with fluvastatin derivative. Thus, the aim of present work is to synthesize and characterize Co(II), Ni(II), Cu(II), Mn(II) and Fe(III) metal complexes with newly synthesized Schiff base derived from isatin monohydrazone and fluvastatin, possessing donor sites of carbonyl oxygen and azomethine nitrogen. The electron transfer mechanism of the metal complexes is investigated by the aid of cyclic voltammetry. The Schiff base and its metal complexes were screened for their antimicrobial activity.

2. EXPERIMENTAL PART

2.1. Physical measurements

Carbon, hydrogen and nitrogen were estimated by using Elemental Analyzer Carlo Erba EA1108 analyzer. The IR spectra of the Schiff base and its metal complexes were recorded on a HITACHI-270 IR spectrophotometer in the 4000-250 cm^{-1} region in KBr disc. The electronic spectra of the complexes were recorded in HPLC grade DMF and DMSO on a VARIAN CARY 50-BIO UV-spectrophotometer in the region of 200-1100 nm. The ^{1}H-NMR spectrum of the ligand was recorded in d$_6$-DMSO on a BRUKER 300 MHz spectrometer at room temperature using TMS as an internal reference. FAB-Mass spectra were recorded on a JEOL SX 102/DA-6000 mass spectrometer/data system using Argon/Xenon (6 kV, 10A) as the FAB gas. The accelerating voltage was 10 kV and the spectra were recorded at room temperature and m-nitrobenzyl alcohol was used as the matrix. The mass spectrometer was operated in the positive ion mode. Molar conductivity measurements were recorded on ELICO-CM-82 T Conductivity Bridge with a cell having cell constant 0.51 and magnetic moment was carried out by using Faraday balance.

Electrochemical behavior of the metal complexes was investigated with CH Instruments, U.S.A (Model 1110A-Electrochemical analyzer, Version 4.01) in HPLC grade DMF containing n-Bu_4NClO_4 as the supporting electrolyte. The three-electrode system consisted of glassy carbon electrode (3 mm diameter) as a working electrode, a Ag/AgCl (3 M KCl) reference electrode and a platinum wire as auxiliary electrode was used. In order to provide a reproducible active surface and to improve the sensitivity and resolution of the voltammetric peaks, the glassy carbon electrode was polished to a mirror finish with 0.3 micron alumina on a smooth polishing cloth and then rinsed with methanol and double distilled water prior to each electrochemical measurements. The electrode cleaning procedure requires less than 3 min. All the solutions examined by electrochemical techniques were purged for 10 min with water-saturated nitrogen. All measurements were carried out at room temperature (24 ^{0}C).

2.2. Materials

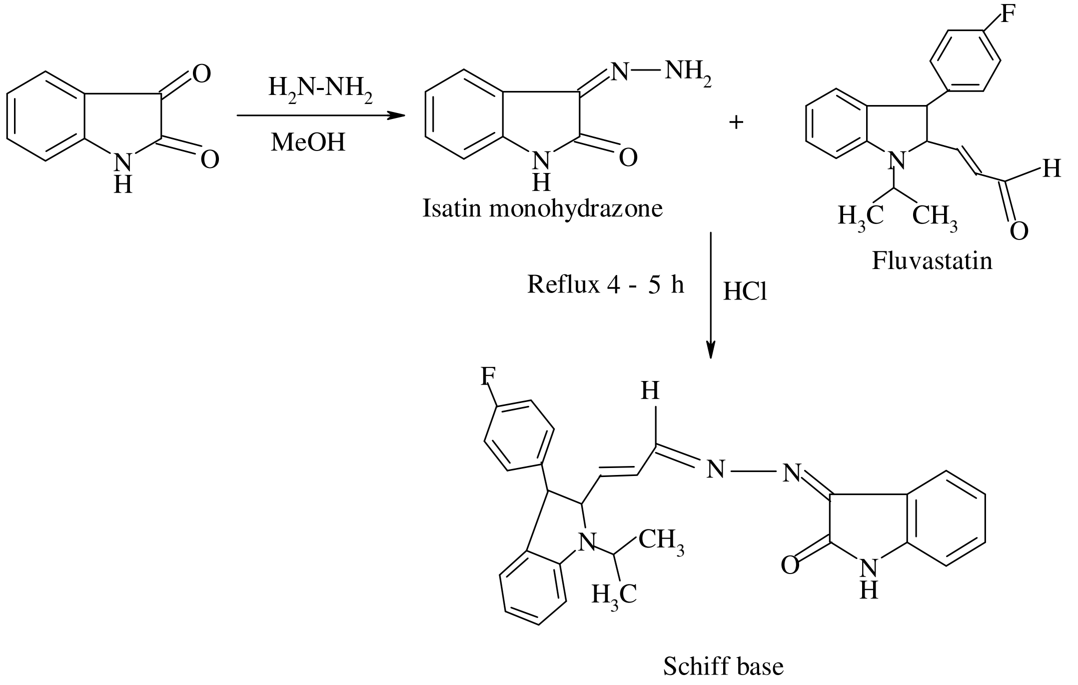
All the chemicals used were of reagent grade. Isatin was recrystallized before using.

2.2.1. Synthesis of isatin monohydrazone

Isatin (1.47 g, 10 mmol) was dissolved in methanol (40 mL) and was added to a solution of hydrazine hydrate (0.05 g, 10 mmol) dissolved in hot methanol (10 mL). The resulting mixture was refluxed for 3 h on a water-bath. On cooling, the yellow compound that formed was filtered, washed, dried and recrystallized from methanol. m.p. 225 ^{0}C (yield 95%).

2.2.2. Synthesis of Schiff base

The synthesis of Schiff base is schematically presented in scheme 1. The Schiff base has been synthesized by refluxing the reaction mixture of hot methanolic solution (30 mL) of fluvastatin (0.01mol) and hot methanolic solution (30 mL) of isatin monohydrazone (0.01mol) for 4-5 h with 3-4 drops of hydrochloric acid. The product obtained after the evaporation of the solvent was filtered, washed with cold MeOH and recrystallized from MeOH. m.p. 278 ^{0}C (Yield 78%)



Scheme 1. Synthesis of Schiff base

2.2.3. Synthesis of Co(II), Ni(II), Cu(II), Mn(II) and Fe(III) complexes [1-5]

Hot methanolic solution (35 mL) of Schiff base (2 mmol) was mixed with hot methanolic solution (15 mL) of $CoCl_2.6H_2O/NiCl_2.6H_2O/$ $CuCl_2.2H_2O/MnCl_2.4H_2O/FeCl_3.6H_2O$ (1 mmol) and refluxed on water bath for 2h. Then, to the reaction mixture 2 mmol of sodium acetate was added and refluxion was continued for 2h. The separated complex was filtered, washed thoroughly with water, methanol and dried in vacuum over fused $CaCl_2$. Yield of the metal complexes lie in the range of 68-73% (Table 1).

2.3. In vitro antibacterial and antifungal assay

The biological activities of synthesized Schiff base and its Co(II), Ni(II), Cu(II), Mn(II) and Fe(III) metal complexes have been studied for their antibacterial and antifungal activities by agar and potato dextrose agar diffusion method respectively. The antibacterial and antifungal activities were done at 100, 200 and 500 µg/mL concentrations in DMF solvent by using four bacteria (*E. coli, S. aureus, P. aeruginosa* and *Bacillus subtilis)* and two fungi (*A. niger* and *P. Chrysogenum)* by the minimum inhibitory concentration (MIC) method [17]. These bacterial strains were incubated for 24h at 37ºC and fungi strains were incubated for 48h. at 37ºC. Standard antibacterial (Strepto*mycine*) and antifungal drug (*Nyastatin*) was used for comparison under similar conditions. Activity was determined by measuring the diameter of the zone showing complete inhibition (mm).

3. RESULTS AND DISCUSSION

The formation of complexes of $CoCl_2.6H_2O/NiCl_2.6H_2O/CuCl_2.2H_2O/$ $MnCl_2.4H_2O/FeCl_3.6H_2O$ with Schiff base in MeOH is presented in the following reaction.

$$M.Cl_2.nH_2O + 2\,L \rightarrow ML_2.2Cl + nH_2O$$

M = Co(II), Ni(II), Cu(II) and Mn(II)

$$FeCl_3.nH_2O + 2\,L \rightarrow [FeL_2.2Cl\,]Cl + nH_2O$$

All the metal complexes are stable and non-hygroscopic in nature. The complexes are insoluble in common organic solvents but soluble in DMF and DMSO. The elemental analyses shows that, the Co(II), Ni(II), Cu(II) and Mn(II) complexes have 1:2 stoichiometry of the type $ML_2.2Cl$ and Fe(III) complex is of the type $[FeL_2.2Cl].Cl$ wherein L acts as a bidentate ligand. The molar conductance values are too low to account for any dissociation of the complexes in DMF, indicating the non-electrolytic nature of the complexes in DMF (Table 1).

Table 1. Elemental analyses of Schiff base and its metal complexes along with molar conductance and magnetic moment data.

Comp.	Empirical formula	Colour/Yield %	M%		C%		H%		N%		Molar conductance Ohm^{-1} cm^{2} mole^{-1}	μ_{eff} (BM)
			Obsd	Calcd	Obsd.	Calcd	Obsd.	Calcd	Obsd.	Calcd		
L	$C_{28}H_{23}N_4OF$	78%	-	-	74.598	74.832	5.121	5.122	12.367	12.472	-	-
1	$[Co(C_{28}H_{23}N_4OF)_2.2Cl]$	Brown / 70%	5.689	5.744	65.415	65.433	4.368	4.479	10.895	10.905	19.22	4.76
2	$[Ni(C_{28}H_{23}N_4OF)_2.2Cl]$	Yellowish green / 71%	5.661	5.653	65.268	65.479	4.321	4.483	10.912	10.916	22.25	3.28
3	$[Cu(C_{28}H_{23}N_4OF)_2.2Cl]$	Dark Green/ 73%	6.112	6.110	65.108	65.179	4.299	4.462	10.635	10.863	23.67	1.76
4	$[Mn(C_{28}H_{23}N_4OF)_2.2Cl]$	Light Yellow/ 69%	5.398	5.474	65.439	65.682	4.390	4.496	10.612	10.948	23.4	5.92
5	$[Fe(C_{28}H_{23}N_4OF)_2.2Cl]Cl$	Black/68 %	5.286	5.288	63.212	63.456	4.197	4.343	10.473	10.576	21.63	5.04

3.1. I.R. Spectral studies

The prominent infrared spectral data of Schiff base and its metal complexes are presented in Table 2. The IR spectra of the Schiff base exhibited characteristic band due to *ν*(NH) and lactonyl carbon *ν*(C=O) at 3190 cm^{-1} and 1722 cm^{-1} [18] respectively. In addition, the strong band at 1614 cm^{-1} and a characteristic high intensity band at 1621 cm^{-1} in the IR spectra of the Schiff base are assigned to *ν*(C=N) and *ν*(HC=N) respectively.

Table 2. The important infrared frequencies (in cm^{-1}) of Schiff base and its metal complexes.

Compound	Indol ring ν (NH)	Lactonyl ν (C=O)	ν (HC=N)	ν (C=N)	ν (M-N)	ν (M-O)	ν (M-Cl)
$C_{28}H_{23}N_4OF$	3190	1722	1621	1614	-	-	-
$[Co(C_{28}H_{23}N_4OF)_2.2Cl]$	3192	1704	1602	1612	452	512	352
$[Ni(C_{28}H_{23}N_4OF)_2.2Cl]$	3190	1698	1598	1613	461	518	345
$[Cu(C_{28}H_{23}N_4OF)_2.2Cl]$	3191	1697	1603	1614	480	526	362
$[Mn(C_{28}H_{23}N_4OF)_2.2Cl]$	3193	1702	1601	1613	472	510	370
$[Fe(C_{28}H_{23}N_4OF)_2.2Cl]Cl$	3190	1701	1596	1614	464	530	358

In comparison with the spectra of the Schiff base, all the Co(II), Ni(II), Cu(II), Mn(II) and Fe(III) complexes exhibited the band of *ν*(HC=N) in the region 1596-1603 cm^{-1}; showing the shift of band to lower wave numbers indicating that, the azomethine nitrogen is coordinated to the metal ion [19, 20]. The band of *v*(C=O) in the region 1697-1704 cm^{-1} in the metal complexes showing the shift to lower wave numbers confirms that, the carbonyl oxygen is coordinated to the metal ion [20, 21]. The unaltered position of a band due to *v*(NH) and *v*(C=N) in all the metal complexes indicates that, these groups are not involved in coordination. The new bands in the region of 452-480 and 510-530 cm^{-1} in the spectra of the complexes are assigned to stretching frequencies of (M-N) and (M-O) bonds respectively [22]. Another band in the region 345-370 cm^{-1} is ascribed to (M-Cl) bond formation [23].

Thus the IR spectral results provide strong evidences for the complexation of Schiff base with metal ions in bidentate mode.

3.2. NMR study of Schiff base

In the ^1H NMR spectrum of the Schiff base, the NH proton of isatin exhibited signal at 10.2 ppm (s, 1H) and the characteristic signal observed at 8.6 ppm (s, 1H) is due to azomethine proton. The multiplet signals around 6.4-7.5 ppm are ascribed to aromatic protons. The signals observed at 2.4 ppm are due to methyl protons. Thus the n.m.r. results further supports the i.r. inferences.

3.3. Electronic Spectral and magnetic studies

The electronic spectra of Co(II) complex exhibited absorption bands in the region 8000-10000 cm^{-1} and 18000-20000 cm^{-1} corresponding to ν_1 and ν_3 transitions respectively, which are attributed to the transitions $^4T_{1g}$ (F) → $^4T_{2g}$ (F) (ν_1); ^4T_1g (F) → ^4T_1g (P) (ν_3). In the present investigation, brownish Co(II) complex show the absorption bands at 9542 and 19282 cm^{-1} corresponding to ν_1 and ν_3 transitions respectively. These bands are the characteristic of high spin octahedral Co(II) complex [24]. However, ν_2 band is not observed because of its proximity to strong ν_3 transition. The magnetic measurement of Co(II) complex exhibited magnetic moment value of 4.76 which is within the octahedral range of 4.3-5.2 BM. [25].

The greenish Ni(II) complex exhibited three bands at 10415, 15645 and 26342 cm^{-1} which are attributed to the $^3A_{2g} \rightarrow {}^3T_{2g}$ (ν_1); $^3A_{2g} \rightarrow {}^3T_{1g}$ (F) (ν_2) and $^3A_{2g} \rightarrow {}^3T_{1g}$ (P) (ν_3) transitions respectively indicating octahedral geometry around Ni(II) ion [26]. Ni(II) complex showed the magnetic moment value of 3.28 which is within the range of 2.8-3.5 BM suggesting [25] consistency with their octahedral environment.

The Electronic spectra of Cu(II) complex display two prominent bands. A low intensity broad band around 14476 cm^{-1} is assignable to $^2T_{2g} \leftarrow {}^2E_g$ transition. Another high intensity band at 25562 cm^{-1} is due to symmetry forbidden ligand → metal charge transfer. On the basis of electronic spectra distorted octahedral geometry around Cu(II) ion is suggested [27]. The Cu(II) complex showed magnetic moment 1.76 BM, is slightly higher than the spin-only value 1.73 BM expected for one unpaired electron, which offers possibility of an octahedral geometry [28].

Eletronic spectra of the Mn(II) complex display weak absorption bands at 18615 (ν_1), 23684 (ν_2), 27769 (ν_3) and 38890 cm^{-1} (ν_4) characteristic of octahedral geometry corresponding to $^6A_{1g} \rightarrow$

$^4T_{1g}(^4G)$, $^6A_{1g}\rightarrow {}^4E_g(4D)$, $^6A_{1g}\rightarrow {}^4T_{1g}(^4P)$, $^6A_{1g}\rightarrow {}^4E_g(G)$ transitions, respectively. The complex shows magnetic moment in the range 5.92 B.M.

The electronic spectra of the Fe(III) complex showed strong bands at 17932 and 13122 cm^{-1}. It was not possible to identify the type of the d–d transition. This is due to a strong charge-transfer (CT) band tailing from the UV-region to the visible region. The magnetic moment of the Fe(III) complex was observed is 5.04 B.M., lower than the magnetic moment of the high spin octahedral complex. Generally, a tentative interpretation expects the structure of Fe (III) to be an octahedral geometry [29].

3.4. FAB-mass spectral studies

The FAB-mass spectrum of Schiff base showed a molecular ion peak m/z at 449 which is equivalent to its molecular weight. The fragmentation peaks, at m/z 290, 251, and 157 are ascribed to the cleavage of $C_8H_5ON_3$, C_3H_3N and C_6H_4F respectively, are well observed in the mass spectrum.

The spectrum of $[Co(C_{28}H_{23}N_4OF)_2.2Cl]$, $[Ni(C_{28}H_{23}N_4OF)_2.2Cl]$, $[Cu(C_{28}H_{23}N_4OF)_2.2Cl]$, $[Mn(C_{28}H_{23}N_4OF)_2.2Cl]$ and $[Fe(C_{28}H_{23}N_4OF)_2.2Cl]Cl$ showed a molecular ion peak M^+ at m/z 1027, 1026, 1031, 1023 and 1059 respectively that is equivalent to its molecular weight. The Co(II), Ni(II), Cu(II) and Mn(II) complexes gave a fragment ion peak with loss of 2 chlorine atoms at m/z 957, 956, 961 and 953 respectively. In case of Fe(III) complex the peak observed at m/z 1024 is due to loss of one chlorine atom. This fragment ion further by losing two chlorine atoms gave a fragment ion peak at m/z 954. All these fragments leading to the formation of the species $[ML_2]^+$ which undergoes demetallation to form the species $[L]^+$ gave fragment ion peak at m/z 449.

3.5. ESR studies of Cu(II) complex

The ESR spectral studies of Cu(II) complex provides information of the metal ion environment. The ESR spectrum of the Cu(II) complex was recorded in DMSO at liquid nitrogen temperature (LNT) and at room temperature (RT). The spectrum at RT shows one intense absorption band in the high field region and is isotropic due to the tumbling motion of the molecules. However, this complex at LNT shows four well resolved peaks in low field region. The $g_{\|}$ and $g_{\perp}$ values have been found to be 2.1016 and 2.011 respectively. These values indicate that the unpaired electron lies predominantly in the $d_{x^2-y^2}$ orbital [30]. The trend $g_{\|} > g_{\perp} > 2.0023$ observed for the complexes indicate that the unpaired electron is localized in the $d_{x^2-y^2}$ orbital of the Cu(II) ion and are characteristic for the axial symmetry. The g_{av} was calculated to be 2.0436. Thus the results suggested that, the Cu(II) complex possess distorted octahedral geometry.

3.6. Electrochemical studies

The Co(II) complex exhibits one electron quasi reversible transfer process with a reduction peak at E_{pc}= -1.5V with a corresponding oxidation peak at E_{pa}= -0.7V at a scan rate of 50mV/s (Figure 1). The peak separation (ΔE_p) of this couple is 0.8V. With the increasing scan rates, ΔE_p value also increases giving further evidence for the quasi-reversible Co(II)/Co(I) couple. The difference between forward and backward peak potentials can provide a rough evaluation of the degree of the reversibility. The ratio of cathodic to anodic peak height was less than one. However, the peak current increases with the increase of the square root of the scan rates. This establishes the electrode process as diffusion controlled.

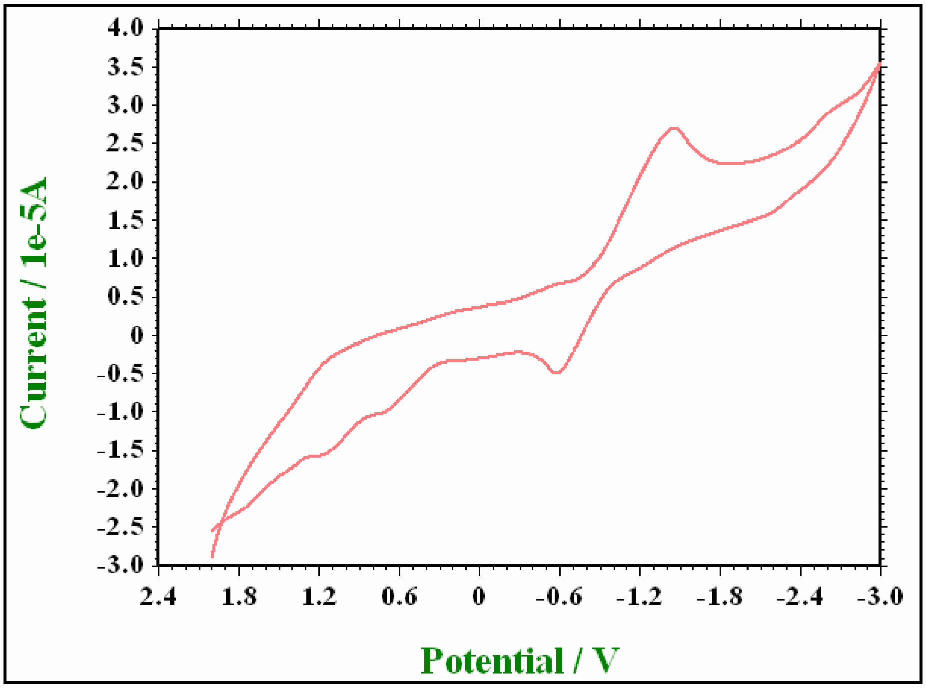


Figure 1. Cyclic voltammogram of Co(II) complex.

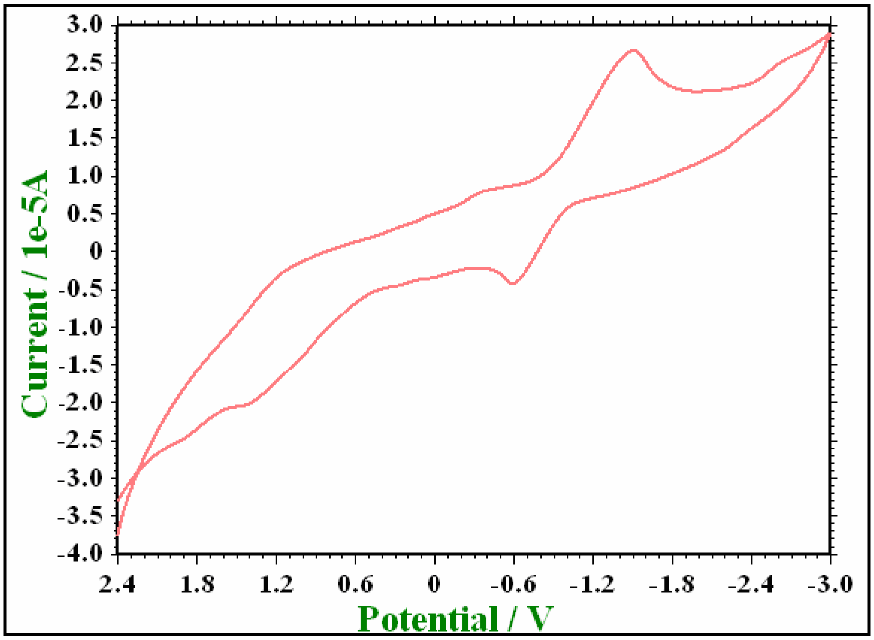


Figure 2. Cyclic voltammogram of Cu(II) complex

A cyclic voltammogram of Cu(II) complex is presented in Figure 2. Voltammogram displays a reduction peak at E_{pc}= -1.4V with an associated oxidation peak at E_{pa}= -0.6V at a scan rate of 50mV/s. The peak separation of this couple (ΔE_p) is 0.8V and increases with scan rate. The ΔE_p is 1.1 and 1.4 at scan rates 100mV/s and 200mV/s respectively. Thus, the analyses of cyclic voltametric responses at different scan rate give the evidence for quasi-reversible one electron reduction. The most significant feature of the Cu(II) complex is the Cu(II)/Cu(I) couple. The ratio of cathodic to anodic peak height was less than one. However, the peak current increases with the increase of the square root of the scan rates. This establishes the electrode process as diffusion controlled [31].

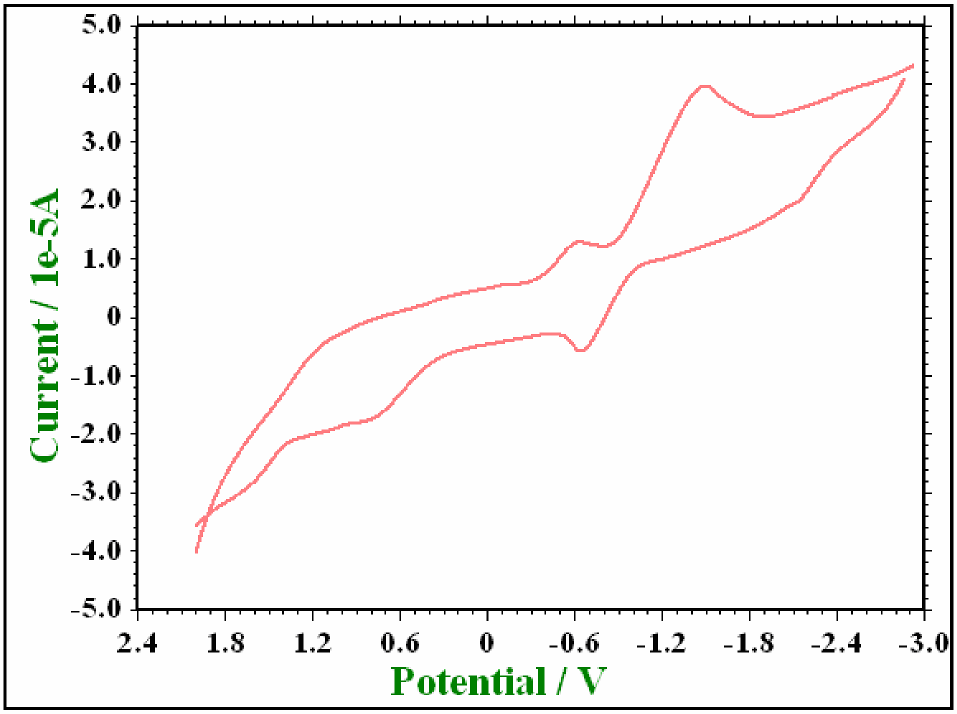


Figure 3. Cyclic voltammogram of Mn(II) complex.

The redox property of the Mn(II) complex was studied in the potential range of +1.8 to -2.0 V. Cyclic voltammogram of Mn(II) complex is shown in Figure 3. The Mn(II) complex is electroactive with respect to the metal center and exhibited two redox processes, each reduction is associated with a single-electron transfer process at room temperature [32, 33]. For both responses, the cathodic and anodic peak heights are equal, and vary as the square root of the scan rate; E_{pc} and E_{pa} are virtually independent of the scan rate. Two well-defined quasi-reversible one-electron cyclic responses were observed at E_{pc} = -1.4808 with a corresponding oxidation peak at E_{pa}= -0.6542V and at E_{pc} = -0.5981 with a corresponding oxidation peak at E_{pa}= 0.8174V respectively at a scan rate of 100mV/s. The electrochemical behavior shows moderately high reduction potentials. ΔE_p values for the first redox couple, 0.8266V is higher than for the second redox couple, 0.2193V. E_p value is higher for the complex due to the difference between the original complex and the reduced species.

The Fe(III) complex exhibited two quasi-reversible peaks. The representative c.v. of Fe(III) complex is shown in Figure 4. A cyclic voltammogram of Fe(III) displays two reduction peaks, first one at E_{pc}= -0.7213 V with an associated oxidation peak at E_{pa}= 0.4162 V and second reduction peak at E_{pc}= -1.6721 V with an associated oxidation peak at E_{pa} = -0.5839 V corresponding to the Fe(III)/Fe(II) and Fe(II)/Fe(I) respectively at a scan rate of 0.2V/s. The value of ΔE_p is 0.3051 and 1.0882 for first and second redox couples respectively and increases with scan rate giving evidence for quasi-reversible nature associated with one electron reduction.

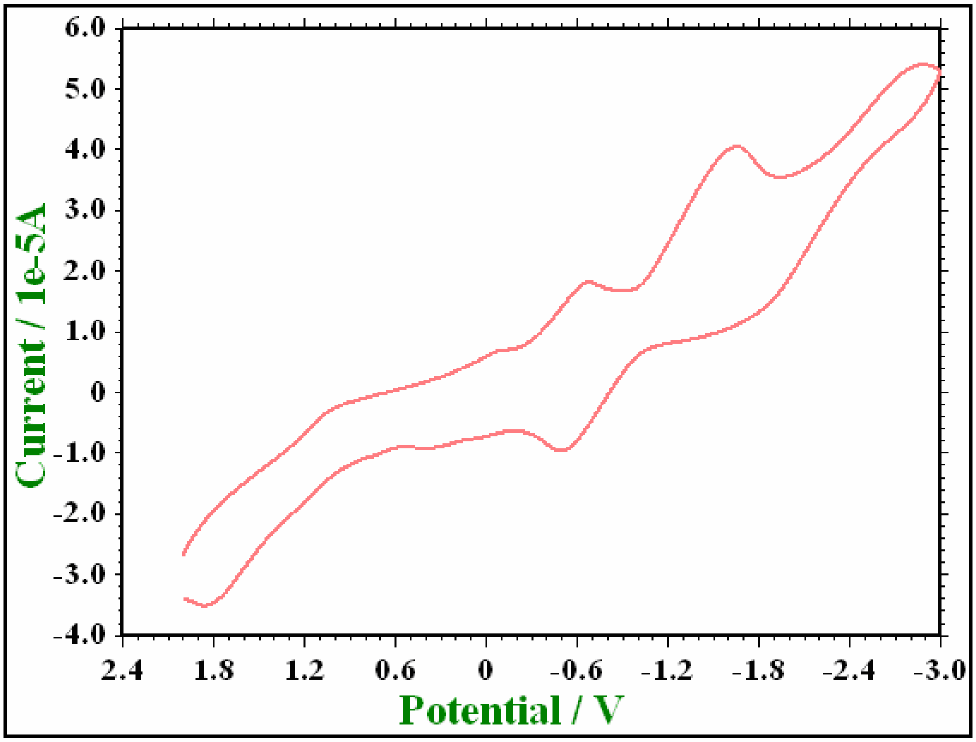


Figure 4. Cyclic voltammogram of Fe(III) complex

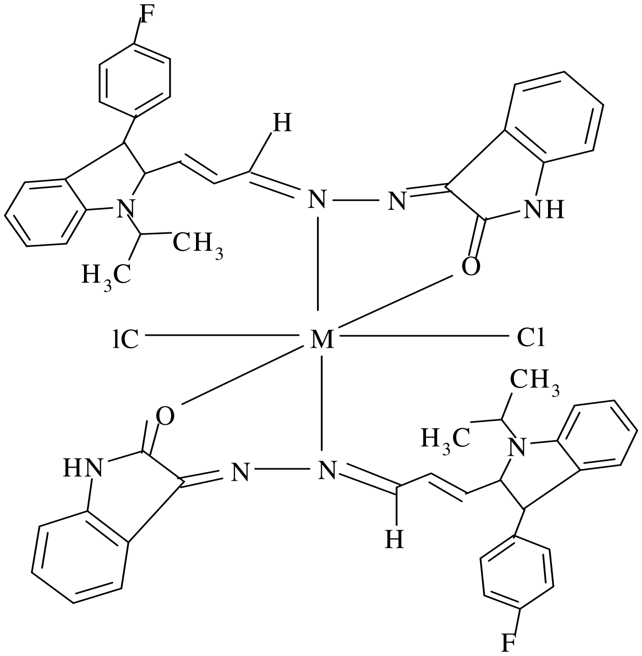
3.7. In-vitro antimicrobial assay

The antimicrobial results are systematized in Table 3. From the antibacterial studies it is inferred that, the Schiff base was found to be potentially active against *S. aureus* and *B. subtitles.* Some of the complexes shown high antibacterial activity against *S. aureus* and *B. subtilis*. In case of antifungal activity, the Schiff base and their complexes were found to be inactive. It is evident from the results that, the biological activity of some of the metal complexes is higher than the ligands. This enhancement in the activity of the metal complexes can be explained on the basis of chelation theory [34]. It is, however, known that the chelating tends to make the Schiff base act as more powerful and potent bactereostatic agents, thus inhibiting the growth of bacteria and fungi more than the parent Schiff base [35-37].

Table 3. Antimicrobial results of Schiff base and its metal complexes

Compound	Conc. (μg ml^{-1})	Growth Inhibition against Bacteria in mm				Growth Inhibition against Fungi in mm	
		S. aureus	*B. subtilis*	*P. auregenosa*	*E. coli*	*A. Niger*	*P. Crysogenum*
$C_{28}H_{23}N_4OF$	100	11	11	8	8	10	8
	200	15	10	8	9	10	8
	500	19	14	11	11	12	7
$[Co(C_{28}H_{23}N_4OF)_2.2Cl]$	100	11	9	8	8	12	9
	200	10	8	6	9	8	9
	500	15	14	6	10	8	7
$[Ni(C_{28}H_{23}N_4OF)_2.2Cl]$	100	10	11	7	8	10	7
	200	13	9	7	8	10	9
	500	20	13	7	7	10	10
$[Cu(C_{28}H_{23}N_4OF)_2.2Cl]$	100	8	9	8	8	8	9
	200	8	9	8	10	8	9
	500	12	16	10	10	8	9
$[Mn(C_{28}H_{23}N_4OF)_2.2Cl]$	100	11	14	8	10	10	8
	200	13	10	7	10	10	8
	500	14	15	10	8	7	7
$[Fe(C_{28}H_{23}N_4OF)_2.2Cl]Cl$	100	11	11	7	8	10	8
	200	13	10	7	7	8	8
	500	12	10	9	7	10	8
Streptomycin	500	28	29	35	25	-	-
Nyastatin	500	-	-	-	-	26	25

Less than 12mm - inactive; 12–16mm - moderately active; above 16mm - highly active.



M = Co(II), Ni(II), Cu(II) and Mn(II)

Figure 5. Structure of metal complexes

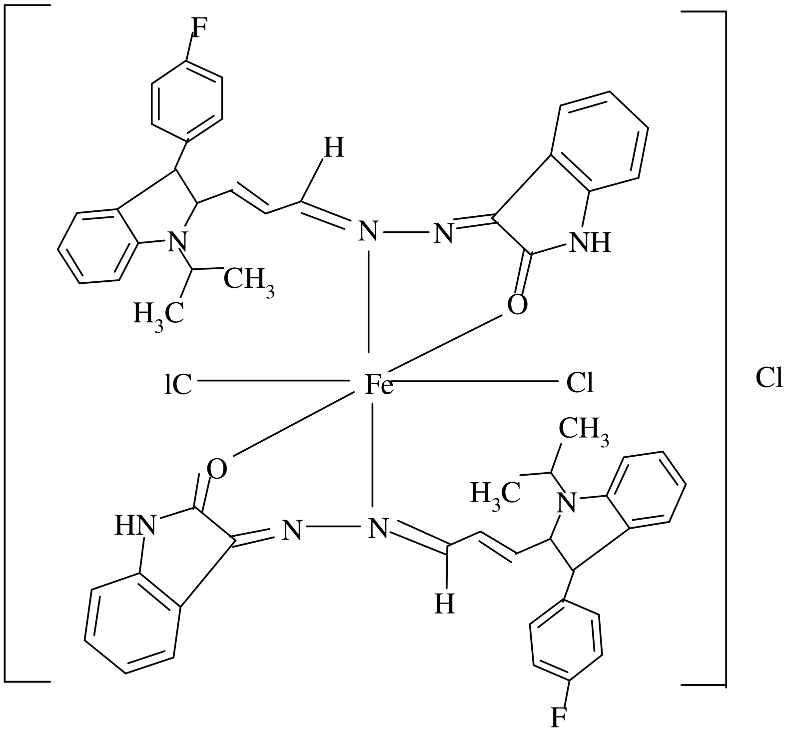


Figure 6. Structure of Fe(III) complex

4. CONCLUSIONS

In this study, the first complexes of Co(II), Ni(II), Cu(II), Mn(II) and Fe(III) complexes with Schiff base derived from fluvastatin and isatin monohydrazone were synthesized and characterized. The Schiff base act as versatile bidentate ligand. On the basis of different techniques, the structure of the complexes is proposed (Figures 5 & 6).

The electrochemical properties of the metal complexes revealed the quasi-reversible one electron/two electron transfer redox process. The Schiff base and some of the metal complexes were found to be active against some of the representative bacterial and fungal strains.

References

1. R.W. Daisley, V.K. Shah, *J. Pharm. Sci.,* 73 (1984) 407.
2. S.N. Pandeya, D. Sriram, E. Declecq, C. Pannecouque, M. Mitvrouw, *Indian J. Pharm. Sci.,* 60 (1999) 207.
3. S.N. Pandeya, J.R. Dimmock, *Pharmazie,* 48 (1993) 659.
4. R. Boon, *Antiviral Chem. Chemother.*, 8 (1997) 5.
5. S.N. Pandeya, D. Siram, G. Nath, E. Declercq, *Eur. J. Pharm. Sci.,* 9 (1999) 25.
6. D.X. West, A.K. El-Sawaf, G.A. Bain, *Tran. Met. Chem.,* 23 (1998) 1.
7. R. Oljan, P. Kapa, T.L. George, *Org. Process Research & Development,* 5 (2001) 519.

8. K.H. Thompson, C. Orvig, *J. Chem. Soc., Dalton Trans.,* (2006) 761.
9. M.B. Ferrari, G.G. Fava, P. Tarasconi, R. Albertini, S. Pinelli, R. Starcich, *J. Inorg. Biochem.,* 53 (1994) 13.
10. M.C. Rodrigues-Arguelles, M.B. Ferrari, F. Bisceglie, C. Pelizzi, G. Pelosi, S. Pinelli, M.Sassi, *J. Inorg. Biochem.,* 98 (2004) 313.
11. G. Cerchiaro, K. Aquilano, G. Filomeni, G. Rotilio, M.R. Ciriolo, A.M.D.C. Ferreira, *J. Inorg. Biochem.,* 99 (2005) 1433.
12. J.M. Kauffmann, J.C.Vire, *Anal. Chim. Acta.,* 273 (1993) 329
13. J. Wang, (Ed.) *Electroanalytical Techniques in Clinical Chemistry and Laboratory Medicine,* VCH, New York, 1988
14. P.T. Kissinger, W.R. Heineman, *Laboratory Techniques in Electroanalytical Chemistry,* 2nd Edition, Marcel Dekker, New York, 1996.
15. B.S. Garg, P.K. Singh, S.K. Garg, *Indian J. Chem.,* 30A (1991) 979.
16. G.M. Abu El-Reash, F. Taha, A.M. Shallaby, O.A. El-Gamal, *Indian J. Chem.,* 30A (1991) 286.
17. A.K. Sadana, Y. Mirza, K.R. Aneja, O. Prakash, *Eur. J. Med. Chem.*, 38 (2003) 533.
18. S. Neena, H. Sunita, S. Jyoti, P. Vanita, B.V.Agarwala, *Synth. React. Inorg. Met.-Org. Chem.,* 22 (1992) 1283.
19. K. Nakamoto, *Infrared spectra of Inorganic and Coordination Compounds,* Wiley-Interscience: New York, 1970.
20. B. Murukan, S.K. Bhageerethi, M. Kochukittan, *J Coord. Chem.,* 60;15 (2007) 1607.
21. G. Cerchiaro, P.L. Saboya, A.M.C. Ferreira, D.M. Tomazela, M.N. Eberlin, *Tran. Met. Chem.,* 29 (2004) 495.
22. A. Hatzidumitrious, C.A. Bolos, *Polyhedron,* 17 (1998) 1779.
23. M.J. Kharodawala, A.K. Rana, *Synth. React. Inorg. Met.-Org. and Nano-met. Chem.,* 33 (2003) 1483.
24. K. Singh, M.S. Barwa, P. Tyagi, *Eur. J. Med. Chem.,* 41 (2006) 147.
25. P.P. Dholakiya, M.N. Patel, *Synth. React. Inorg. Met.-Org. and Nano-Met. Chem.,* 32;4 (2002) 819.
26. K.E.M. Saied, *Ind. J. Chem.,* 33A (1994) 830.
27. H. Liu, H. Wang, F. Gao, D. Niu, Z. Lu, *J. Coord. Chem.,* 60;24 (2007) 2671.
28. D.P. Singh, R. Kumar, V. Malik, P. Tyagi, *Trans. Met. Chem.,* 32 (2007) 1051.
29. F.A. Cotton, G. Wilkinson, *Advanced Inorganic Chemistry,* A Comprehensive Text, 4th edn., John Wiley and Sons, New York, 1986.
30. R.L. Dutta, A. Syamal, *Electron spin resonance responses, In Elements of Magnetochemistry,* 2nd Ed.; East-West Press: New Delhi, 1992; pp. 206–250.
31. A.J. Bard, L.R. Izatt (Eds), *Electrochemical Methods: Fundamentals and Applications,* 2nd ed., (Wiley, New York, 2001).
32. M. Donzello, D. Dini, G. Arcangelo, C. Ercolani, R. Zhan, Z. Ou, P. Stuzhiz, K.J. Kadish, *J. Am. Chem. Soc.,* 125 (2003) 14190.
33. B.W. Rossister, J.F. Hamilton, *Physical Method of Chemisty,* 2nd Ed.; Wiley: New York, 1985; p. 2.
34. K.N. Thimmaiah, W.D. Lloyd, G.T. Chandrappa, *Inorg. Chim. Acta.,* 106 (1985) 81.
35. A. Kulkarni, P.G. Avaji, G.B. Bagihalli, P.S. Badami, S.A. Patil, *J. Coord. Chem.,* 62;3 (2009) 481.
36. A.D. Kulkarni, S.A. Patil, P.S. Badami, *J. Sulf. Chem.,* (2009) In Press.
37. Z.H. Chohan, H. Pervez, A. Rauf, K.M. Khan, C.T. Supuran, *J. Enz. Inhib. Med. Chem.,* 19 (2004) 417.