www.sphinxsai.com

International Journal of ChemTech Research
CODEN(USA): IJCRGG ISSN : 0974-4290
Vol.4, No.4, pp 1571-1581, Oct-Dec 2012

Synthesis, Characterization, Redox and Biological Screening studies of copper(II), nickel(II), cobalt(II), zinc(II) and vanadium(IV) complexes derived from 1-phenyl-2,3-dimethyl-4-imino-(2-hydroxybenzylidene)-pyrozol-5-(α-imino)-indole-3-propionic acid

Thavuduraj Kavitha[1], Antonysamy Kulandaisamy[2,*]
and Ponnusamy.Thillaiarasu[3]

[1]**Department of Chemistry, Sri Ramasamy Naidu Memorial college,**
Sattur - 626203, India
[2]**Department of Chemistry, Raja Doraisingam Government Arts College,**
Sivagangai -630561, India.
[3]**Department of Chemistry, Kalasalingam university,**
Krishnan koil - 626190, India

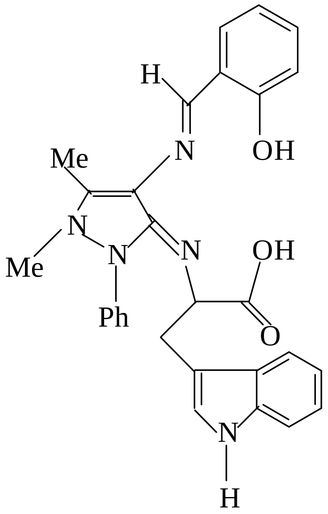
Corres.author: kulandai.kvn@gmail.com

Abstract: Neutral tetradentate N_2O_2 complexes of Cu(II), Ni(II), Co(II), Zn(II) and VO(II) have been synthesized using the 1-phenyl-2,3-dimethyl-4-imino-(2-hydroxybenzylidene)-pyrozol-5-(α-imino)-indole-3-propionic acid (H_2L). All the complexes were characterized by elemental analysis, molar conductivity, magnetic susceptibility data, IR, ^{1}H-NMR, UV-Vis, FAB-Mass, and EPR spectral studies. The physico-chemical studies and spectral data indicate that the ligand acts as a divalent tetradentate chelating agent. All the complexes have the general composition [ML)] (M= Cu(II), Ni(II), Co(II), VO(II) and Zn(II); L = Schiff base). The IR, UV-Vis., magnetic susceptibility measurements and EPR spectral data of the complexes suggest that all the complexes are square planar geometry around the central metal ion except VO(II) complex which has square pyramidal geometry. The lower conductivity data confirm the non-electrolytic nature of the complexes. The effect of redox potential on metal ion by the ligand environment is studied by cyclic voltametric measurements. The Schiff base and its metal complexes were utilized to test the *in vitro* antimicrobial activities, which gave good results in the presence of metal ion than the free ligand environment against the different species of microorganisms.

Keywords: Tryptophan, Salicylidene-4-aminoantipyrine, Cyclic voltammogram, ESR spectra, Biological screening studies.

Introduction

The transition metal complexes of 4-aminoantipyrine and its complexes have been extensively examined due to their wide applications in various fields like biological, pharmacological, clinical, analytical and industrial area.[1-6] Schiff base itself have some antimicrobial activity which have been enhanced by chelating it with metal ion.[7] A search through the literature reveals that no work has been done on the transition metal complexes of Schiff bases formed by the condensation of salicylidene-4-aminoantipyrine with tryptophan.[8-20] We report herein the synthesis, characterization, redox and antimicrobial studies of transition metal complexes containing Schiff base derived from salicylidene-4-aminoantipyrine and tryptophan. The synthesized ligand is N_2O_2 donor type and its ligation behavior with different metal ions was studied. The proposed structure of the Schiff base is shown in scheme 1.



Scheme 1. The proposed structure of the Schiff base (H_2L)

Experimental

All the chemicals used for the synthesis were of Merck products and used as supplied. Spectroscopic grade solvents were used for spectral and cyclic voltammetric measurements. FAB mass spectra were recorded on a JEOL SX 102/DA-6000 mass spectrometer, using m-nitrobenzyl alcohol as a matrix, at Indian Institute of Chemical Technology, Hyderabad. Elemental analyses (C, H and N) were carried out with Thermofinger –Flash CA 1112 series at Sophisticated Analytical Instrumentation facility, Indian Institute of Technology, Mumbai. The molar conductance of the complexes in 10^{-3} M MeCN solution was measured using a 305 type systronic conductivity bridge with a dip type cell. H^1-NMR spectra of the Schiff base and its zinc complexes were recorded in $CDCl_3$ solution on a Brucker 300 MHz FT-NMR spectrometer using TMS as internal standard at Madurai Kamaraj University, Madurai. The UV-Visible spectra of the compounds were recorded on a Shimadzu UV-1601 spectrophotometer. The IR spectra were recorded on a FT-IR 8400S Shimadzu spectrophotometer in the 4000 – 400 cm^{-1} range using KBr as solvents. Cyclic voltammogram of the complexes was recorded in MeCN solution at 300 K using a BAS CV50 electrochemical analyzer. The three electrode cell contains a reference Ag/AgCl electrode, Pt wire auxiliary electrode and glassy carbon working electrode. Tetra butyl ammonium bromide (TBAB) was used as supporting electrolyte. The X-band ESR spectra of the copper and vanadyl complexes in MeCN solution at 300 K and 77 K were recorded on a Varian E-112 ESR spectrometer using TCNE (Tetra cyanoethylene) as the g – marker at Sophisticated Analytical Instrumentation facility, IIT, Mumbai.

Synthesis of Schiff base

An ethanolic solution (50 ml) of 1-phenyl-2,3-dimethyl-4-imino-(2-hydroxybenzylidene)-pyrozol-5-one (salicylidene-4-aminoantipyrine ; 3.07 gms, 0.01 mol) and α-amino indole-3-propionic acid (tryptophan; 2.04 gms, 0.01 mol) was boiled under reflux on a water bath for 2 hrs. Then the resulting solution was concentrated to 10 ml and stirred with 5 ml of (30 %) ammonia solution. The solid obtained was collected by filtration and recrystallized from ethanol.

Synthesis of complexes

An ethanolic solution of $CuCl_2$/$NiCl_2$/$CoCl_2$/ $ZnCl_2$/$VOSO_4$ (0.05 mol) and Schiff base (0.05 mol) was stirred for 3 hrs and then concentrated to 10 ml. The mixture was cooled at room temperature for 12 hrs and the precipitated complexes was filtered, washed and recrstallised from ethanol.

Biological Screening studies

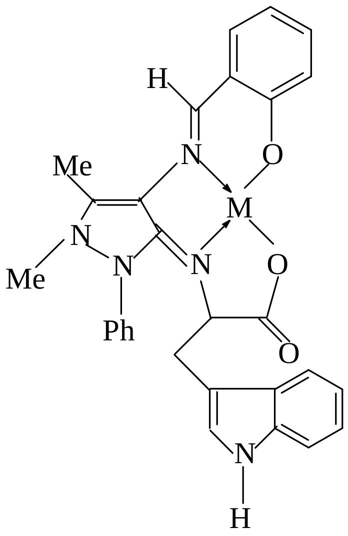
The *in-vitro* biological screening effects of the investigated compounds were tested against the bacteria (*Escherichia coli, Salmonella typhi, Staphylococcus aureus*, *Starptococci* and *Pseudomonas aeruginosa*) and fungi (*Aspergillus* *niger* and *Candida albicans*) by disc diffusion method using nutrients agar as the medium. The stock solutions were prepared by dissolving the compounds in MeCN and the solutions are serially diluted in order to find the minimum inhibitory concentration values (MIC). All the blank discs were moistened with the solvent. For disc assays, the compounds containing disc (6 mm) with various concentrations were placed on the surface of the nutrient agar plate previously spread with 0.1 ml of overnight culture of microorganisms. Then, the plates were incubated at 37 ^{o}C for 48 hrs. During this period, the test solution was diffused and affected the growth of the microorganisms. Hence, the inhibition zones were developed on the plate around the disc. The concentration at which the zone developed was noted as MIC values of the synthesized compounds.

Result and discussion

The analytical data for the ligand and complexes together with some physical properties are summarized in Table 1. The analytical data of the complexes correspond well with the general formula ML, where M = Cu(II), Ni(II), Co(II), Zn(II) and VO(II); L = $C_{29}H_{25}N_5O_3$. The magnetic susceptibility data of the complexes in the solid state shows that Cu(II), Co(II) and VO(II) are paramagnetic, Ni(II) and Zn(II) are diamagnetic at room temperature. The lower conductivity values of the chelates support the non-electrolytic nature of the metal complexes.[21]

Mass spectra

The FAB mass spectral data (m/z values) of the Schiff base and its copper complex were compared with their molecular formula weight. The mass spectra of Schiff base and its copper complex show a molecular ion peak at 493 and 555 m/z respectively. These data are in good agreement with the proposed molecular formula for these complexes *i.e.,* [$MC_{29}H_{25}N_5O_3$], where M= Cu(II), Ni(II), Co(II), VO(II) and Zn(II). In addition to molecular ion peak, the spectra exhibited peaks assignable to various fragments arising from the thermal cleavage of the ligand and its complex. The proposed structure of the complexes is given in scheme 2.



Scheme 2. The proposed structure of the complexes, where M = Cu(II), Ni(II), Co(II), Zn(II) and VO(II).

Table 1. Physical characterization, analytical, molar conductance and magnetic susceptibility data of the Schiff base and its complexes

Compound	Colour	Yield (%)	Melt./ Decomp. Point (^{o}C)	Found (Calcd) (%)				Λ_M x 10^{-3} (mho cm^2 mol^{-1})	$\mu_{eff..}$ (B.M.)
				M	C	H	N		
H_2L	Red	65	115	-	70.18 (70.59)	5.44 (5.48)	14.54 (14.2)	-	-
[CuL]	Green	70	240	11.23 (11.46)	62.73 (62.75)	4.62 (4.51)	12.48 (12.62)	2.74	1.78
[NiL]	Pale green	75	145	10.58 (10.68)	63.24 (63.31)	4.48 (4.55)	12.68 (12.73)	1.73	-
[CoL]	Brown	71	234	10.65 (10.72)	63.21 (63.28)	4.35 (4.55)	12.81 (12.73)	2.02	3.86
[VOL]	Green	69	295	9.31 (9.13)	62.13 (62.37)	4.29 (4.48)	12.42 (12.55)	2.40	1.73
[ZnL]	Red	76	180	11.68 (11.75)	62.59 (62.55)	4.36 (4.49)	12.58 (12.62)	2.77	-

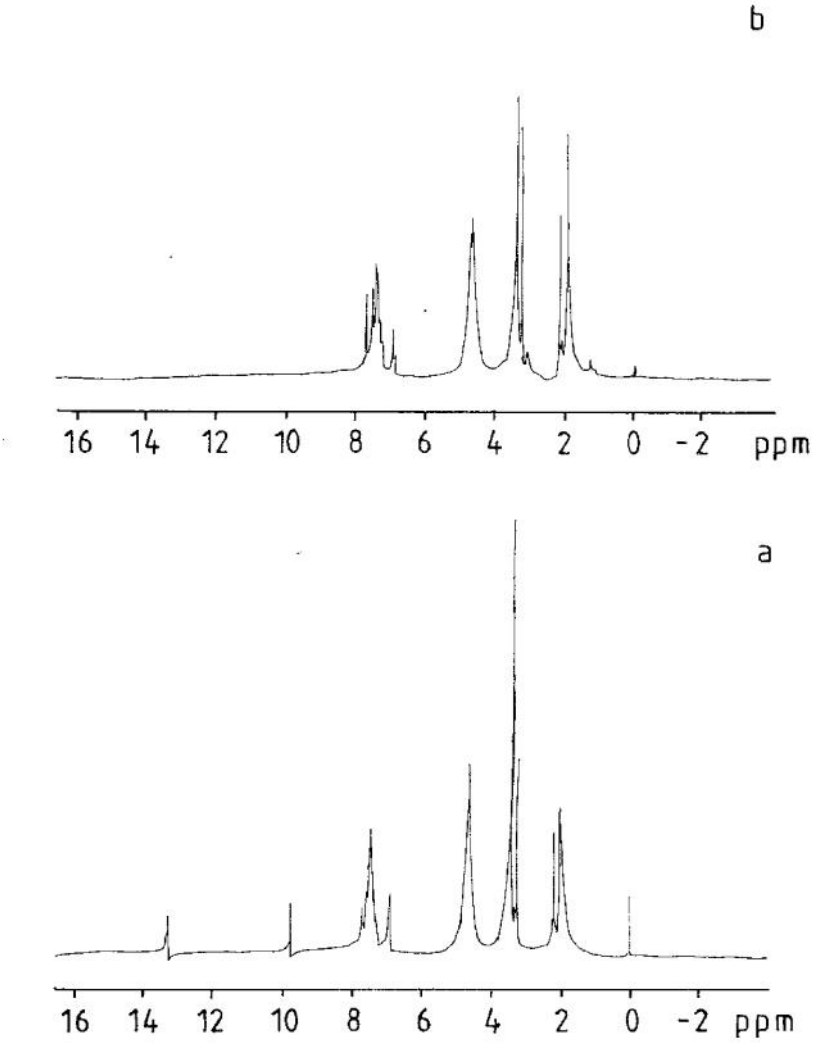


Fig. 1 - ^{1}H-NMR spectra of the Schiff base (H_2L) and zinc complex in $CDCl_3$ solution.

H^1-NMR spectra

H^1-NMR spectra of the Schiff base (H_2L) and its zinc complex were recorded in $CDCl_3$ solution (Fig. 1). The Schiff base shows two peaks at 9.77 ppm and 13.35 ppm which are attributable to the phenolic – OH group of salicylaldehyde and -COOH group of tryptophan moiety respectively. Absence of these two peaks in the zinc complex which favours the loss of phenolic – OH and -COOH proton due to the coordination with zinc ion. A slight down field shift was noted in all other signals in the zinc complex.

IR Spectra

The IR spectrum of the ligand shows a merged strong band at 3500- 3300 cm^{-1} region which are assigned to phenolic –OH group of salicylaldehyde and -COOH group of tryptophan moiety. Disappearance of these bands indicates the deprotonation of these groups upon coordination. IR spectrum of all complexes shows a new strong band at 3150 cm^{-1} region which are assigned to cyclic –NH- group of tryptophan moiety and the same peak is also appeared in the IR spectrum of ligand as a weak node due to merging of –OH groups. It indicates that there is a free existence of this group and not involved in coordination with metal ion. In the spectrum of the Schiff base, the strong bands at 1615 - 1600 cm^{-1} region are attributable to -C=N groups. On chelation, due the possible drift of lone pair electron density towards the metal ion, the azomethine -C=N band is expected to absorb at lower frequency in the complex. The observed band at 1591 - 1512 cm^{-1} region indicates the coordination of azomethine nitrogen to the metal. Moreover, the Schiff base and all the complexes exhibit an intense peak at 1645 cm^{-1}, a characteristic feature of the –C=O stretching frequency indicating the existence of –C=O of acid group in trytophen moiety. IR spectra of the complexes also show a new peaks at 510 cm^{-1} and 430 cm^{-1} region due to the formation of M-N and M-O bond respectively.[22] In addition to other bands, the vanadyl complex shows it characteristic V=O frequency at 960 cm^{-1} region.[23]

Electronic Spectra

The electronic spectrum of the Schiff base in MeCN shows two predominant bands at 279 nm and 366 nm region, which are assigned as intra ligand charge transfer (INCT) bands. The UV-Vis., spectra of copper complex in MeCN solution shows a well defined shoulder at 431 nm and strong broad band at 722 nm, which are assignable to $^2B_2g \rightarrow {}^2B_1g$ and $^2B_2g \rightarrow {}^2A_1g$ transition respectively. It reveals that the copper complex exists in square planar geometry.[24] It also shows two predominant INCT bands at 289 nm and 340 nm.

The electronic spectrum of nickel complex in MeCN shows three bands at 299 nm, 359 nm and 634 nm. Comparisons of this spectrum with the free ligand origin, first two bands are assignable to INCT transitions and the remaining one occurring at 634 nm region is due to $^1A_{1g} \rightarrow {}^1B_{1g}$ transition which confirms square-planar geometry of the nickel complex. The observed zero magnetic moment also confirms the square planar environment for the nickel (II) complex, in conformity with the fact that all known square planar complexes of nickel (II) are diamagnetic.[25]

The cobalt complex in MeCN solution shows three prominent bands at 296 nm, 341 nm and 659 nm. The two strong bands in the lower wave length region are assignable to INCT transitions. The ground state configuration for the d^7, Co^{2+} ion is ^4F. The electronic absorption spectrum of the cobalt complex in MeCN show only one d-d band at 654 nm ($^1A_1g \rightarrow {}^1T_1g$) which reveals that the cobalt complex is present in square planar environment.[26]

The optical spectrum of vanadyl complex in MeCN solution shows four bands at 286 nm, 344 nm, 430 nm and 786 nm. The last two bands are assigned as $^2B_2 \rightarrow {}^2E$ and $^2B_2 \rightarrow {}^2A_1$ transition respectively which is consistent with that of square pyramidal geometry.[26] The other two higher energy transitions are assigned as INCT. This is further confirmed by the magnetic susceptibility value (1.76 BM).

Redox studies

Cyclic voltammetry helps to evaluate the effect of ligands on the redox potential of the central metal ion in complexes. The electrochemical reversible nature of the Cu(II)/Cu(III) or VO(II)/VO(III) redox systems in complexes depends on the nature of the ligand. Cyclic voltammetry has been shown to be a particularly useful technique in studies of this type, aiding one to measure the existence of short lived species, as well as to study the ligand's structural parameters such as size and degree of conjugation.

Cyclic voltammogram of the Cu(II) and VO(II) complexes were recorded in MeCN solution using TBAB as supporting electrolyte. The scan rates were varied from 25 to 1000 mVs^{-1}. Several peaks were observed in the cathodic and anodic sections of the cyclic voltammogram. The plot of peak currents of all the peaks was correlated with the square root of the sweep rate, resulting in a straight line in all the complexes. This demonstrates the diffusion controlled mass transport.

The cyclic voltammogram of the copper complex in MeCN solution (Fig. 2) shows a reversible peak for the couple: Cu(II) → Cu(III) at Ep_a = 0.58 V with the direct cathodic peak for Cu(III) → Cu(II) at Ep_c = 0.53 V. Further, it exhibits two irreversible peaks characteristic for Cu(II) → Cu(I) (Ep_c = - 0.50 V) and Cu(I) → Cu(0) (Ep_c = - 0.96 V) reduction. In the anodic side, the direct oxidation of Cu(0) → Cu(II) is observed with a strong stripping peak at Ep_a = - 0.42 V. The two-electron transfer nature of the process is established by the comparison of Ip_c and Ip_a values.[27]

The cyclic voltammogram of the vanadyl complex in MeCN solution (Fig. 3) shows a well defined redox process corresponding to the formation of the VO(II)/VO(III) couple at Ep_a = 0.80 V and the associated cathodic peak at Ep_c = 0.63 V. This couple is found to be quasi reversible and the ratio of anodic to cathodic peak currents (Ip_c/Ip_a = 0.94) is corresponding to simple single-electron transfer process. This complex also shows another quasi reversible peak in the negative region characteristics for VO(II) → VO(I) reduction at Ep_c = - 0.72 V with the associated anodic peak at Ep_a = -0.61 V for VO(I) → VO(II) oxidation.[28,29]

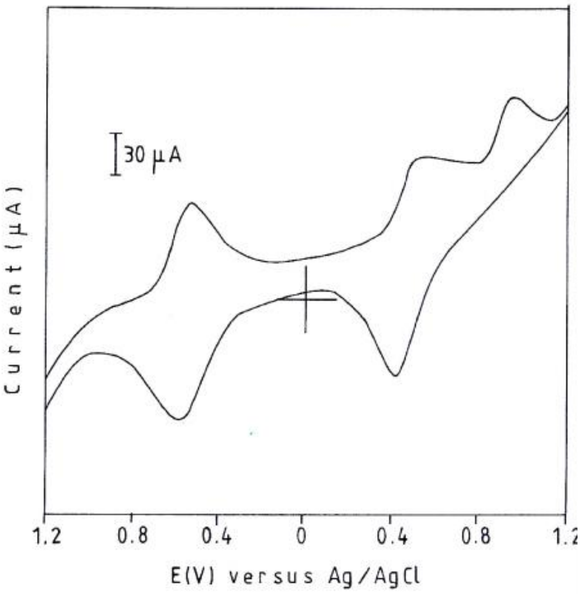


Fig. 2 - The cyclic voltammogram of the copper complex in MeCN solution (0.1 M TBAB; scan rate 100 mVs^{-1}).

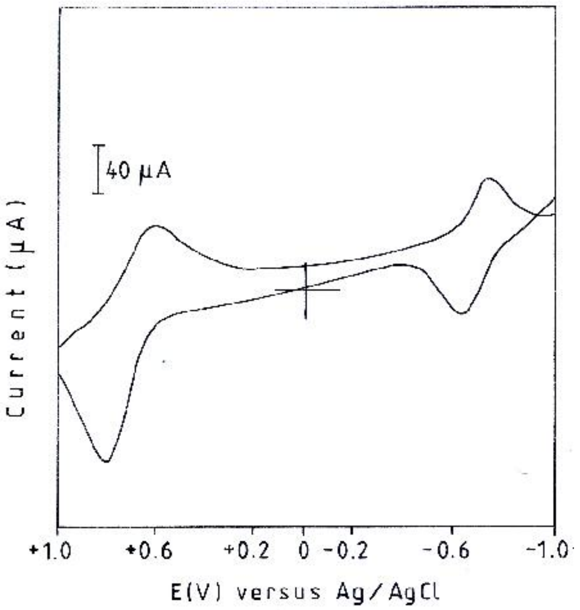


Fig. 3 - The cyclic voltammogram of the vanadyl complex in MeCN solution (0.1 M TBAB; scan rate 100 mVs^{-1}).

ESR Specra

The X-band ESR spectra of copper complex in MeCN at a concentration of ca. 0.1 mol was recorded at 300 K and 77 K are shown in Fig. 4. The spectrum of the copper complex at 300 K shows one intense band in the high field region, which are isotropic due to tumbling motion of the molecules. The splitting of intense peak at 300 K may be due to internal standard (TCNE). However this complex at 77 K shows well-resolved peaks with low intensities in the parallel region and one intense peak in perpendicular region. The absence of a half field signal at 1600 G corresponding to the ΔMs = ±2 transition, rules out any Cu-Cu interaction in the ESR spectrum. The ESR parameters $g_{\parallel}$, $g_{\perp}$, $A_{\parallel}$ and $A_{\perp}$ were determined from the anisotropic spectra of the frozen solutions (magnetically diluted solids). The g tensor values of the copper complexes can be used to derive the ground state. In square planar complexes, the unpaired electron lies in the $dx^{2}-y^{2}$ orbital giving $^{2}B_{1}g$ as the ground state with $g_{\parallel} > g_{\perp} > 2$, while the unpaired electron lies in the d_{z}^{2} orbital giving $^{2}A_{1}g$ as the ground state with $g_{\perp} > g_{\parallel} > 2$. From the observed values, it is clear that $A_{\parallel}$ (150×10^{-4} cm^{-1}) > $A_{\perp}$ (83×10^{-4} cm^{-1}) and $g_{\parallel}$ (2.37) > $g_{\perp}$ (2.059) > 2 and the parameters of the complex coincide well with related systems which suggest that the complex has square planar geometry and the system is axially symmetric.[30,31]

The ESR parameters and the d-d transition energies were used to evaluate the bonding parameters α^{2}, β^{2} and γ^{2} for the Cu(II) ion in various ligand field environments which may be regarded as measures of the covalence of the in-plane σ-bonds (α^{2}), in-plane π-bonds (β^{2}) and out-of-plane π-bonds (γ^{2}) respectively.[32] The observed value of α^{2} (0.84) indicates that complex have some covalent character. The observed β^{2} (1.02) and γ^{2} (0.95) values indicate that there is no substantial interaction between the out-of-plane π-bonding and in-plane π-bonding which are completely ionic.

The ESR spectra of the vanadyl complex were recorded in MeCN solution at 300 and 77 K and are shown in Fig.5. The room temperature (300 K) spectrum is a typical eight line pattern which shows that single vanadium is present in the molecule, *i.e.* it is a monomer. In the frozen solid state, the spectrum shows two types of resonance component: one set due to the parallel features and the other set due to the perpendicular features. It shows an axially symmetric anisotropy with well resolved sixteen-line hyperfine splitting characteristic of an interaction between the electron and the vanadium nuclear spin.

The various parameters calculated from the spectra of the complex [$A_{\parallel}$ (193×10^{-4} cm^{-1}) > $A_{\perp}$ (86×10^{-4} cm^{-1}) and $g_{\perp}$ (2.02) $g_{\perp}$ (1.90)] indicate that the complex is square pyramidal geometry, characteristic for the oxovanadium (IV) chelates. The bonding parameters of this complex can be calculated with the help of optical spectra of the complex.[33]

The in-plane π-bonding β^2 (1.02) and out-of-plane π-bonding coefficients γ^2 (0.98) values do not deviate much from unity. This is consistent with Kivelson's conclusion, which suggests that the d_{xy} orbital is essentially non-bonding while π-bonding coefficients remain constant. Essentially, the delocalization of electrons into the ligand may be gauged form the in-plane σ-bonding coefficients (α^2) values. This follows the σ-donor strength of the ligand and it usually decreases as the covalent bonding increases. The observed α^2 (0.85) value indicates that the in-plane σ-bonding is significant. The molecule orbital coefficients also show that the metal ion has some covalent character in ligand environment.

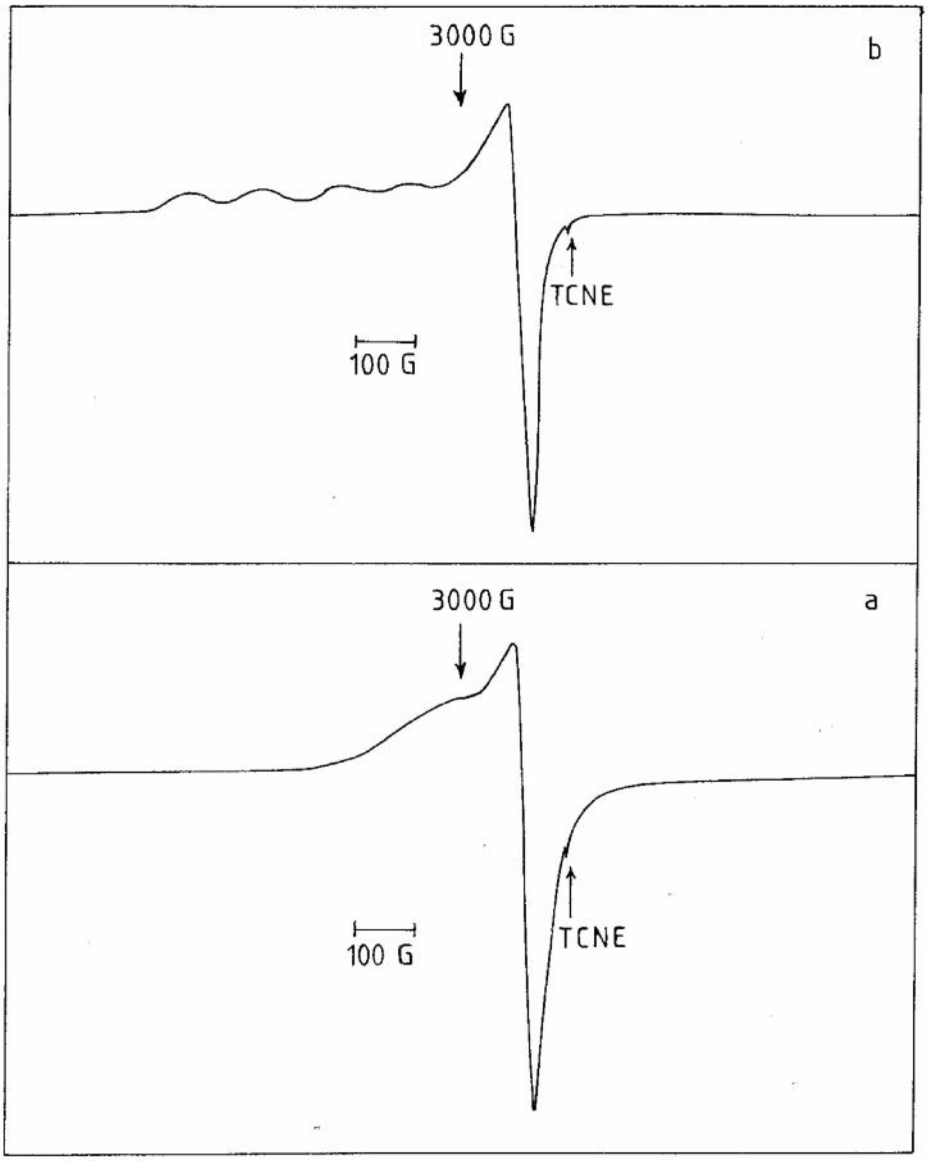


Fig.4 - The ESR spectra of copper complex at 300 K (a) and 77 K (b) in MeCN solution

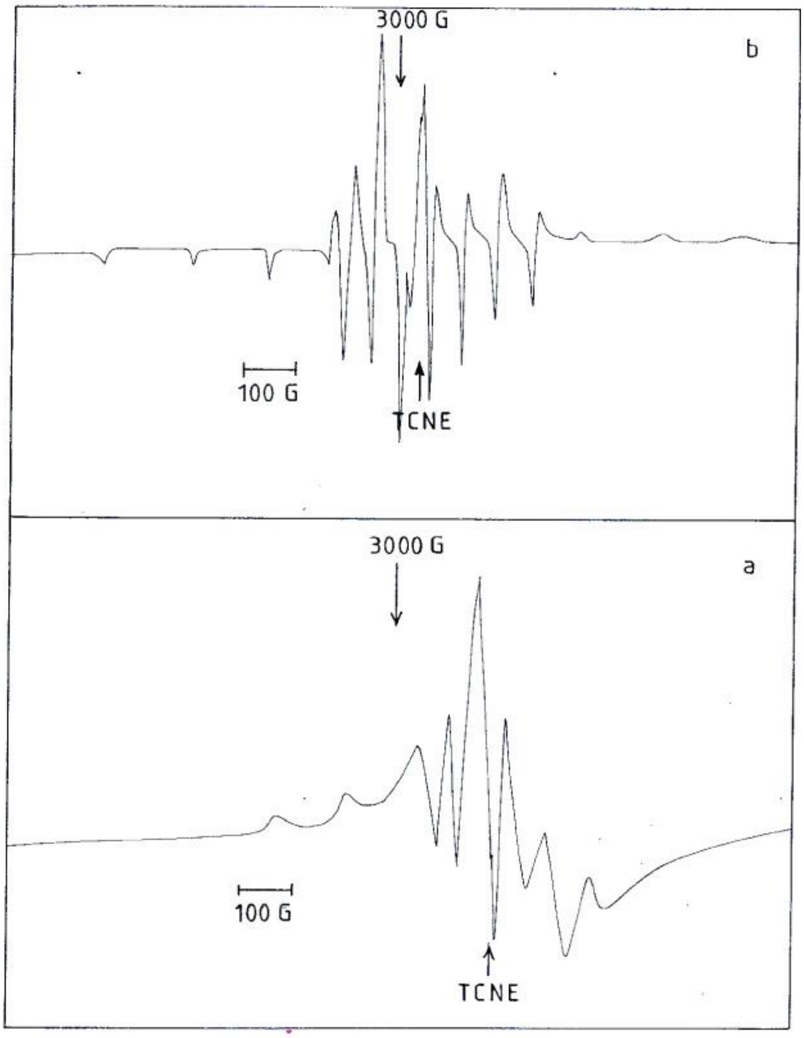


Fig.5 - The ESR spectra of vanadyl complex at 300 K (a) and 77 K (b) in MeCN solution

Biological screening studies

The *in-vitro* biological screening effects of the investigated compounds were tested against the various bacteria such as *Escherichia coli, Salmonella typhi, Staphylococcus aureus, Starptococci*, and *Pseudomonas aeruginosa* and fungi *Candida albicans* and *Aspergillus niger* by disc diffusion method. The minimum inhibition concentration value of the compounds against the growth microorganisms are summarized the Table 2.

A comparison of the *MIC* value of ligand with its complexes indicates that the metal chelates exhibited higher antimicrobial activity than ligand and the control sample. Such increased activity of the complexes can be explained based on the Overtone's concept and the Tweedy chelation theory.[34] According to the Overtone's concept of cell permeability, the lipid membrane that surrounds the cell favors the passage of only lipid-soluble materials, due to which liposolubility is an important factor that controls antimicrobial activity. On chelation, the polarity of the metal ion will be reduced due to the partial sharing of positive charges with donor groups. Furthermore, it increases the delocalization of π-electrons over the whole chelate ring that enhances the lipophilicity of the complexes. This increased lipophilicity enhances the penetration of the complexes into lipid membranes and the blocking of the metal binding sites in the enzymes of microorganisms.[35] Due to the presence of more functional groups (hydroxyl groups and azomethine groups), which forms hydrogen bonding with proteins present in the cell walls of the organisms, resulting in interference with the normal cell process.[36-38] Comparatively, zinc complex shows higher activity than all other complex which is due to its higher lipid solubility.[39]

Table 2. Antimicrobial activities of Schiff base and its metal complexes (MIC in µmg)

Compound	*Escherichia coli*	*Salmonella typhi*	*Pseudomonas aeruginosa*	*Staphylococcus aureus*	*Starptococci*	*Aspergillus niger*	*Candida albicans*
H_2L	60	60	60	60	85	65	100
[CuL]	50	40	50	50	60	50	60
[NiL]	40	45	55	35	50	55	45
[CoL]	35	40	65	35	50	60	50
[VOL]	45	45	55	45	50	55	55
[ZnL]	35	30	45	35	35	35	40

Acknowledgments

The authors express sincere thanks to the Managing Board, Vice-chancellor and Head of the department of chemistry, Kalasalingam University for providing research facilities. One of the authors (A.K.) is grateful to Principal, Head and faculty members, Department of chemistry for their support.

References

1. Ismail K. Z., El-Dissouky A. and Shehada A. Z., Spectroscopic and magnetic studies on some copper(II) complexes of antipyrine Schiff base derivatives. Polyhedron, 1997, 16, 2909-2916.
2. Singh L., Sharma A. and Sindhu S. K., Structure and bonding of some newly synthesized complexes of lanthanide(III) complexes of 4[N-(p-Dimethylaminobenalidene) amino]antipyrine, *Asian J. Chem.*, 1999, 11, 1445-1450.
3. Shankar G., Premkumar P. R. and Ramalingam S. K., 4-aminoantipyrine Schiff base complexes of lanthanide and Uranyl ions, Polyhedron, 1986, 15, 991-994..
4. Chopra J. R., Uppal D., Arrora U. S. and Gupta S. K., Synthesis ectral studies of Cu(II) complexes of 4[N-(2-hydroxy-1-naphthalidene0amino]antipyrine, Asian J. Chem., 2000, 12, 1277-1281.
5. S. Cunha, S. M. Oliveira, M.T. Rodrigues, R. M. Bastos, J. Ferrari, C. M. A. De Oliveira, L. Kato, H. B. Napolitano, I. Vencato, C. Lariucci, Structural studies of 4-aminoantipyrine derivatives. J. Mol. Struct., 2005, 752 32 - 39.
6. Raman N., Mitu L., Sakthivel A. and Pandi M. S. S., Studies on DNA cleavage and antimicrobial screening of transition metal complexes of 4-aminoantipyrine derivatives of N_2O_2 type, J. Iran. Chem. Soc., 2009, 9, 738-748.
7. Raman, N. Raja, J.D., Sakthivel, A., Transition metal complexes with Schiff base ligands: 4-aminoantipyrine based derivatives – A review, J. Coord. Chem., 2009, 62, 691 - 709.
8. Rosu T., Pasculescu S., Laza V., Chifiriuc C. and Cernat R., Copper(II) complexes with ligands derived from 4-amino-2,3-dimethyl-1-phenyl-3-pyrazolin-5-one: Synthesis and biological activity, Molecules, 2006, 11, 904-914.
9. N. Raman, C. Thangaraja, Synthesis, structural characterization, cyclicvoltammetric and antimicrobial studies of tetraaza 13-membered macrocyclic copper(II), cobalt(II), nickel(II) and zinc(II) complexes derived from the Schiff base 3-salicylidene-2,4-di(imino-4'-antipyrinyl)pentane and o-phenylenediamine, *Polish J. Chem.*, 2005, 79, 1123 – 1134.
10. Nag J. K., Pal S. and Sinha C., Synthesis and characterization of cobalt(II), nickel(II), copper(II), palladium(II) and dioxouranium(VI) complexes of the antipyrine schiff base of 3-formylsalicylic acid, Transition Met. Chem., 2005, 30, 523-526.
11. Zambre A. P., Kulkarni V. M., Padhye S., Sandur S. K. and Aggarwal B. B., Novel curcumin analogs targeting TNF-induced NF-@kB activation and proliferation in human leukemic KBM-5 cells, Bioinorg. and Med. Chem., 2006, 14, 7196-7204.
12. Sabaa, M. W., Mohamed, R. R., Oraby, E. H., Vanilin – Schiff bases as organic thermal stabiliser and co-stabilisers for rigid polyvinyl chloride, European Polymer J. 2009, 45, 3072 – 3080.
13. Selvakumar P. M., Suresh E. and Subramanian P. S., Synthesis, spectral characterization and

structural investigation on some 4-aminoantipyrine containing Schiff base Cu(II) complexes and their molecular association**,** Polyhedran, 2007, 26, 749-756.

14. Omar M. M., Mahamed G. G. and Ibrahim A. A., Spectroscopic characterization of metal complexes of novel Schiff base. Synthesis, thermal and biological activity studies**,** Spectrachimca Acta, 2009, 73A, 358 – 369.
15. Padhye S., Yang H., Jamadar A., Cindy Cui Q., Chavan D., Dominiak K., McKinney J., Banerjee S., Ping Dou Q. and Sarkar F. H., New difluoro knoevenagel condensates of curcumin, their Schiff bases and copper complexes as proteasome inhibitors and apoptosis inducers in cancer cells, Pharmaceutical Research, 2009, 26, 1874 – 1880.
16. Deepa K., Madhu N. T. and Radhakrishnan P. K., Cadmium(II) complexes of 1,2-Di(imino-4′-antipyrinyl)ethane, Synth. React. Inorg. Met.-Org. Nano-Met. Chem., 2005, 35, 883 - 888.
17. Ismail K. Z., Synthesis, spectroscopic, magnetic and biological activity studies of copper(II) complexes of an antipyrine schiff base, Transition Met. Chem., 2000, 25, 522 – 528.
18. Agrawal R. K. and Prakash B., Studies on the effect of various anions and diphenyl sulphoxide on the stereochemistry of lanthanide(III) coordination compounds of 4[N-(2'-hydroxy-1'-naphthalidene)amino] antipyrine semicarbazone, Transition Met. Chem., 2005, 30, 696 – 705.
19. Chandra S., Deepali J., Sharma A. K. and Pratibha S., Coordination modes of a schiff base pentadentate derivative of 4-aminoantipyrine with cobalt(II), nickel(II) and copper(II) metal ions: synthesis, spectroscopic and antimicrobial studies, Molecules, 2009, 14, 174-190.
20. Raman N., Syed Ali Fathima S. and Dhaveethuraja J., Designing, synthesis and spectral characterization of Schiff base transition metal complexes: DNA cleavage and antimicrobial activity studies, J. Serb. Chem. Soc., 2008, 73, 1063-1071.
21. Geary W. J., The use of conductivity measurements in organic solvents for the characterisation of coordination compounds, Coord. Chem. Rev., 1970, 7, 81 -122.
22. Nakamoto K., Infrared and Raman Spectra of Inorganic and Coordination Compounds, Wiley Inter science, III Edition, New York, 1977, 296 – 346.
23. Zamian J. R., Dockal E. R., Castellano G. And Oliva G., Synthesis and characterisation of [N,N'-Ethylenebis(3-ethoxysalicylideneaminato]oxovanadium(IV), Polyhedron, 1995, 14, 2411 - 2418.
24. D. U. Warad, C. D. Satish, V. H. Kulkarni, C. S. Bajgur, *Indian J. Chem.*, **39A** (2000) 415 - 420.
25. Lever A.B.P., Inorganic Electronic spectroscopy, Elsevier, II Edition, New York, 1968 355-362.
26. Duta R. L. and Syamal A., Elements of Magnetochemistry, East-west press, II Edition, New Delhi, 1992, 206 – 361.
27. Jeyasubramanian K., Samath S. A., Thambidurai S., Murugesan R. and Ramalingam S. K., Cyclic voltammetric and ESR studies of a tetraaza 14-membered macrocyclic copper(II) complex derived from 3-salicylideneacetylacetone and *o*-phenylenediamine: Stabilization and activation of unusual oxidation states, Transition Met. Chem., 1996, 20, 76 – 80.
28. Dutton K. G., Fallon D. and Murray K. S., Synthesis, structure, ESR spectra and redox properties of [N,N'-ethylenebis (thio salicylidene-aminato)]oxovanadium(IV) and related [S,N] chelates of vanadium(IV), Inorg. Chem., 1988, 27, 34 – 38.
29. P. Knopp, K. Wieghardt, B. Nuber, J. Weiss, W. S. Sheldrick, *Inorg. Chem.*, **29** (1990) 363.
30. Ray R. K. and Kauffman G. R., EPR spectra and covalency of bis(amidinourea/*o*-alkyl-1-amidinourea)copper(II) complexes, Part II. Properties of the $[CuN_4]^{2-}$ chromophore, Inorg. Chim. Acta, 1990, 173, 207 – 214.
31. Srinivasan S., Rajagopal G. and Athappan P. R., Synthesis, spectral and redox properties of metal complexes of macrocyclic tetraza chiral Schiff bases, Transition Met. Chem., 2001, 26, 588 – 593.
32. Sharma A. L., Singh I. O., Singh M. A. and Singh H. R., EPR studies on dichloromono (1-phenyamidino-o-alkylurea)copper(II) complexes. Evidence for field induced partial ordering in the solid state and some unusual features in solution, Transition Met. Chem., 2001, 26, 532 – 537.
33. Yen T. F., Electron Spin Resonance of Metal Complexes, 1st Edn. Plenum Press, New York, 1969.111-133.
34. Anjaneyalu Y. and Rao R. P., Preparation, characterization and antimicrobial activity

studies on some ternary complexes of Cu(II) with acetylacetone and various salicylic acids, Synth. React. Inorg. Met.-Org. Chem., 1986, 16, 257 – 272.

35. Mishra L. and Singh V. K., Synthesis, Characterization and antifungal activity of Co(II), Ni(II), Cu(II) and Zn(II) complexes with new Schiff bases bearing Benzimidazoles, Indian J. Chem., 1993, 37A, 446-449.
36. Thimmaiah, K. N., Chandrappa, Lloyd, W. D., Parkanyi, C., Synthesis and structural investigation of biologically active complexes of 4-acetyl-2-(acetylamino)-5-dimethyl-1,3,4-thiadiazole with Zn(II), Hg(II), Cd(II) and Cu(II), Inorg. Chim. Acta, 1985, 107, 1-4.
37. Dharmaraj N., Viswanathamurthi P. and Natarajan K., Ruthenium(II) complexes containing bidentate Schiff base and their antifungal activity, Transition Met. Chem., 2001, 26, 105 – 109.
38. Malhotra R., Kumar S. and Dhindsa K. S., Synthesis, Characterization and microbiocidal activity of Co(II), Ni(II), Cu(II) and Zn(II) complexes of aryloxyacetic acid and hydrazides, Indian J. Chem., 1993, 32A, 457 – 459.
39. Mohamed G. G. and El-Wahab Z. H. A., Mixed ligand complexes of bis(phenylimine) Schiff base ligands incorporating pyridinium moiety - Synthesis, characterization and antibacterial activity, Spectrachimica Acta, 2005, 61A, 1059 – 1068.

*****