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Catalytic and biological activities of Ru(III) mixed ligand complexes containing N,O donor of 2-hydroxy-1-naphthylideneimines

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Abstract

A series of stable low spin Ru(III) complexes of the type $[RuX_2(EPh_3)_2(L)]$ (where E = P or As; X = Cl or Br; L = mono basic bidentate Schiff bases) have been synthesized and were characterized by analytical, spectral and electrochemical data. A distorted octahedral geometry has been proposed for all the complexes. These complexes catalyze oxidation of primary alcohols and secondary alcohol with high yields in the presence of *N*-methylmorpholine-*N*-oxide (NMO). The ruthenium(III) Schiff base complexes show growth inhibitory activity against the bacteria *Staphylococcus aureus* (209p) and *E. coli ESS* (2231). © 2004 Elsevier B.V. All rights reserved.

Keywords: Ruthenium(III) Schiff base complexes; Spectra; Redox properties; Catalytic oxidation; Antibacterial activity

1. Introduction

Transition metal complexes containing oxygen and nitrogen donor Schiff base ligands have been of research interest for many years [1–4], because of the versatility of their steric and electronic properties, which can be fine tuned by choosing the appropriate amine precursors and ring substituents [5–9]. The accessibility of ruthenium higher oxidation states [10,11] converts them into excellent candidates as catalyst for redox reactions. Particularly, metal complexes of ruthenium have demonstrated to be useful laboratory and industrial homogenous catalysts in the epoxidation of alkenes and oxidation of alcohols using iodosylbenzene, sodiumhypochlorite, hydrogen peroxide and N-methylmorpholine-N-oxide as oxygen sources [12–15]. Further, the oxidation of organic substrates mediated by high valent ruthenium-oxo species evokes much interest in the modelling of cytochrome P-450 [16]. Sharpless et al. [17] carried out a yield oriented study of oxidation of cholesterol, geranial, etc., catalyzed by ruthenium complexes in the presence of

N-methylmorpholine-N-oxide and N-N-dimethylaniline-Noxide. Furthermore, the catalytic activities of ruthenium complexes containing tertiaryphosphine or arsine ligands are well established [18,19]. Chen et al. [20] have proposed that intercalation, hydrogen bonding and $\pi - \pi$ interaction are some of the features implicated in the mode of action of ruthenium complexes as antitumour and antimetastatic agents. In addition, the presence of ruthenium-halogen bonds in several ruthenium complexes exhibiting anticancer activity suggesting that these bonds may also play some important role [21]. In connection with such studies and continuation of our research on synthesis, spectral studies, catalytic and bioactivities of ruthenium complexes with simple and inexpensive ligands [22,23], we describe here the synthesis, characterization and redox properties of ruthenium(III) complexes containing bidentate Schiff bases along with their reactivity towards oxidation of organic substrates in the presence of NMO. The antibacterial activity studies of Schiff bases and their ruthenium complexes were also carried out. The Schiff bases were derived from condensation of 2-hydroxy-1-naphthaldehyde with aniline, o-toluidine, m-toluidine and p-toluidine. The following Schiff bases (Fig. 1) were used to prepare the new ruthenium(III) complexes.

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Fig. 1. Schiff base ligands.

2. Experimental

2.1. Materials

All the reagents used were chemically pure and AR grade. Solvents were purified and dried according to standard procedures [24]. RuCl₃·3H₂O was purchased from Lobachemie Pvt. Ltd., and was used without further purification. 2-hydroxy-1-naphthaldehyde and *N*-methylmorpholine-*N*-oxide were purchased from Aldrich.

2.2. Physical measurements

The analysis of carbon, hydrogen and nitrogen were performed in Carlo-Erba 1106-model 240 perkin-Elmer analyzer at Central Drug Research Institute (CDRI), Lucknow, India. FT-IR spectra were recorded in KBr pellets with a JASCO 400 plus spectrophotmeter in the range 4000-400 cm⁻¹. A Cary 300 Bio UV-vis varian spectrophotometer was used to record the electronic spectra. Room temperature solid state magnetic susceptibilities were measured by using a EG and G model 155 vibrating sample magnetometer at IIT, Chennai. EPR spectra were recorded on JEOL JES-FA200 EPR spectrometer at X-band frequencies for both powder samples and solution at 278 and 77 K, respectively. Electrochemical measurements were made using a Princeton EG and G-PARC model potentiostat using a glassy carbon working electrode and all the potential were referenced to Ag /AgCl electrode. The antibacterial activity studies were carried out at Quest Institute of Life sciences, Nicholas Piramal India Ltd., Mumbai, India. Melting points were recorded with a Boetius micro-heating table and are uncorrected. The ruthenium(III) complexes [RuCl₃(PPh₃)₃] [25], [RuCl₃(AsPh₃)₃] [26], [RuBr₃(AsPh₃)₃] [27] and [RuBr₃(PPh₃)₂(CH₃OH)] [28] were prepared according to the literature reports.

2.3. Preparation of ruthenium(III) complexes

 $[RuX_2(EPh_3)_2(L)]$ (L = monobasic bidentate Schiff base ligand).

All operations were carried out under strictly anhydrous conditions and were prepared by the following general procedure. To a benzene (20 cm^3) solution of $[\text{RuX}_3(\text{EPh}_3)_3]$ (0.12-0.157 g; 0.125 mmol) (E = P, X = Cl; E = As, X = Cl or Br) or $[\text{RuBr}_3(\text{PPh}_3)_2(\text{CH}_3\text{OH})]$ (0.112 g; 0.125 mmol) was added to the appropriate Schiff bases (0.030-0.032 g; 0.125 mmol)(HL₁-HL₄). The solution was allowed to heat

under reflux for 6 h. The reaction mixture gradually changed to deep colour and the solvent was removed under reduced pressure. The residue which was precipitated by addition of pet. ether (60–80 °C) and was recrystallized from CH₂Cl₂/pet. ether (60–80 °C). The compounds were dried under vacuum (yield: 40–60%) and the purity of the complexes was checked by TLC.

2.4. Catalytic oxidation

Catalytic oxidation of primary alcohols to corresponding aldehyde and secondary alcohol to ketone by ruthenium(III) complexes were studied in the presence of NMO as cooxidant. A typical reaction using the complex as a catalyst and benzyl alcohol, cinnamyl alcohol and cyclohexanol as substrates at 1:100 molar ratio is described as follows. A solution of ruthenium complex (0.01 mmol) in 20 cm³ CH₂Cl₂ was added to the solution of substrate (1 mmol) and NMO (3 mmol). The solution mixture was refluxed for 3 h and the solvent was then evaporated from the mother liquor under reduced pressure. The solid residue was then extracted with pet. ether (60–80 °C) (20 cm³) and the ether extracts were evaporated to give corresponding aldehyde which was then quantified as 2,4-dinitrophenylhydrazone derivative [24].

2.5. Procedure for antibacterial activity

The in vitro antibacterial activity of the free ligands and their complexes were tested against the bacteria *Staphylococcus aureus* (209p) and *E. coli ESS* (2231) by well diffusion method using agar nutrient as the medium at 37 °C for 18 h. The Schiff bases and the complexes were stored dry at room temperature and dissolved in 10% DMSO in methanol. In a typical procedure [29] a well was made on the agar medium inoculated with microorganisms. Then the well was filled with the test solutions using a micropipette and the plates were incubated at 35 °C for 24 h for bacteria. During this period, the test solutions were diffused and the growth of the inoculated microorganisms was affected. The inhibition zone developed on the plate was measured.

3. Results and discussion

New hexa-coordinated low spin ruthenium(III) Schiff base complexes $[RuX_2(EPh_3)_2(L)]$ (L = monobasic bidentate Schiff base ligand; E = P or As; X = Cl or Br) were synthesized in good yields from the reactions of $[RuX_3(EPh_3)]$ (E = As; X = Cl or Br, E = P; X = Cl) or $[RuBr_3(PPh_3)_2(CH_3OH)]$ with Schiff base ligands in 1:1 molar ratio in dry benzene is as shown in Scheme 1.

All the complexes are stable in air at room temperature, non-hygroscopic in nature and highly soluble in common solvents such as dichloromethane, acetonitrile, chloroform and DMSO producing intense green solutions. The more solubility of the complexes is may be due to the presence of chlorides







or bromides. The analytical data are listed in Table 1 and are in good agreement with the general molecular formula proposed for all the complexes.

3.1. IR spectra

The IR spectra displayed high intensity bands in the region $1620-1626 \text{ cm}^{-1}$ for free ligands (HL₁-HL₄) are due to $\gamma_{(C=N)}$ vibration mode. These bands shifted to the lower frequency in the range $1596-1617 \text{ cm}^{-1}$ on complexation indicating coordination of the azomethine nitrogen to the metal atom [30,31] and this lowering may be attributed to the decrease in electron density at azomethine group. A strong band observed at ca. $1314-1326 \text{ cm}^{-1}$ in the ligands (HL₁-HL₄) has been assigned to phenolic C–O stretching. On coordination, this band shifts to higher frequency in the range $1334-1340 \text{ cm}^{-1}$ showing that the other coordination

Table 1

Analytical	data of	Ru(III)	Schiff	base	comple	exe

is through the phenolic oxygen atom [30,32]. This fact is further supported by the disappearance of γ_{OH} in the range 3350–3450 cm⁻¹ in all the complexes. Bands in the 550–500 and 450–400 cm⁻¹ regions probably due to formation of M–O and M–N bands, respectively [33]. In addition, the Schiff base complexes show strong vibrations near 520, 695 and 740 cm⁻¹, which are attributed to the triphenylphosphine or triphenylarsine fragments [34].

3.2. Electronic spectra

The electronic spectra of ruthenium(III) complexes were recorded in chloroform in the range 800-200 nm. Most of the complexes showed two to three bands in the region 748-240 nm and are listed in Table 2. The ground state of ruthenium(III) is ${}^{2}T_{2g}$ and the first excited doublet levels in the order of increasing energy are $^2A_{2g}$ and $^2T_{1g},$ arising from $t_{2g}^{4}e_{g}^{1}$ configuration. The spectral profiles below 400 nm are very similar and are ligand-centered transitions. These bands have been designated as $\pi - \pi^*$ and $n - \pi^*$ transitions for the electrons localized on the azomethine group of the Schiff base ligands [35]. In most of the ruthenium(III) complexes the charge transfer bands of the type $L_{\pi y} \rightarrow T_{2g}$ are prominent in the low energy region, which obscures the weaker bands due to d-d transitions [30]. It is therefore difficult to assign conclusively the bands of ruthenium(III) complexes that appear in the visible region. However, the extinction coefficient for the bands in the 748-640 nm region are found to be very low as compared to that of charge transfer bands. Hence, the bands around 748-640 nm have been assigned to ${}^{2}T_{2g} \rightarrow {}^{2}A_{2g}$ transition which is in conformity with assignment made for similar octahedral ruthenium(III) complexes [36–38]. The pattern of the electronic spectra of all the complexes indicates the presence of an octahedral environment around ruthenium(III) ion.

Complexes	Colour	m.p (°C) ^a	Found (calcd.) %			
			C	Н	Ν	
$[RuCl_2(PPh_3)_2(L1)]$	Green	149	67.04 (67.64)	4.33 (4.46)	1.31 (1.49)	
$[RuCl_2(AsPh_3)_2(L1)]$	Green	185	61.57 (61.85)	4.21 (4.08)	1.27 (1.36)	
$[RuBr_2(AsPh_3)_2(L1)]$	Green	124	56.84 (56.21)	4.04 (3.75)	1.42 (1.25)	
$[RuBr_2(PPh_3)_2(L1)]$	Green	188	61.39 (61.69)	4.18 (4.07)	1.61 (1.35)	
$[RuCl_2(PPh_3)_2(L2)]$	Green	133	67.48 (67.91)	4.01 (4.61)	1.66 (1.46)	
$[RuCl_2(AsPh_3)_2(L2)]$	Green	128	62.77 (62.10)	3.73 (4.22)	1.48 (1.34)	
$[RuBr_2(AsPh_3)_2(L2)]$	Green	139	57.51 (57.19)	3.23 (3.88)	1.56 (1.23)	
$[RuBr_2(PPh_3)_2(L2)]$	Green	162	62.43 (62.0)	4.73 (4.21)	1.23 (1.33)	
$[RuCl_2(PPh_3)_2(L3)]$	Green	180	67.47 (67.91)	4.47 (4.61)	1.63 (1.46)	
$[RuCl_2(AsPh_3)_2(L3)]$	Green	122	62.59 (62.17)	4.38 (4.22)	1.27 (1.34)	
$[RuBr_2(AsPh_3)_2(L3)]$	Green	133	57.81 (57.19)	3.23 (3.88)	1.59 (1.23)	
$[RuBr_2(PPh_3)_2(L3)]$	Green	129	62.56 (62.0)	4.58 (4.21)	1.54 (1.33)	
$[RuCl_2(PPh_3)_2(L4)]$	Green	136	67.33 (67.91)	4.89 (4.61)	1.31 (1.46)	
$[RuCl_2(AsPh_3)_2(L4)]$	Green	141	62.41 (62.17)	4.71 (4.22)	1.67 (1.34)	
$[RuBr_2(AsPh_3)_2(L4)]$	Green	151	57.63 (57.19)	3.27 (3.88)	1.23 (1.65)	
$[RuBr_2(PPh_3)_2(L4)]$	Green	178	62.66 (62.08)	4.71 (4.21)	1.57 (1.33)	

^a Decomposition point.

Table 2
IR and electronic spectral data of the Ru(III) Schiff base complexes.

Complexes	$\gamma_{\rm C=N}~({\rm cm}^{-1})$	$\gamma_{C-O} (cm^{-1})$	λ_{max} (ϵ)dm ³ mol ⁻¹ cm ⁻¹
1	1615	1337	405(2216) ^a , 320(3764) ^a
2	1616	1340	$640(400)^*, 420(1200)^a, 318(1800)^c, 242(4900)^b$
3	1616	1334	422(1358) ^a , 312(2283) ^c , 234(10723) ^b
4	1614	1338	440(3852) ^a , 316(8640) ^c , 240(13,680) ^b
5	1597	1335	418(3644) ^a , 314(7142) ^c , 246(15648) ^b
6	1597	1335	748(1500)*, 417(2400)a, 312(8130)c, 259(14090)b
7	1596	1336	742(269) [*] , 568(262) [*] , 316(5020) ^a , 272(8786) ^b
8	1597	1333	522(1262) ^a , 318(5307) ^c , 263(9048) ^c
9	1598	1335	722(1719)*, 410(3556) ^a , 322(5648) ^a , 272(16736) ^b
10	1617	1335	415(7920) ^a , 316(18530) ^c , 288(25070) ^b
11	1598	1335	554(2328) ^a , 320(6276) ^c , 258(12768) ^b
12	1599	1337	732(191) [*] , 415(6690) ^a , 314(14400) ^c , 270(25000) ^b
13	1616	1334	540(3760) ^a , 318(8260) ^c , 268(16,122) ^b
14	1616	1335	740(890)*, 422(2870) ^a , 312(12320) ^c , 276(18220) ^b
15	1597	1335	560(2680) ^a , 416(3840) ^a , 318(11350) ^c , 264(20760) ^b
16	1616	1334	412(4060) ^a , 316(9265) ^c , 281(14085) ^b

* d-d transition.

3.3. Magnetic moment and EPR spectra

The room temperature magnetic moments for some of the complexes were measured and the values for [RuBr₂(AsPh₃)₂(L2)], [RuCl₂(PPh₃)₂(L3)] and [RuBr₂(PPh₃)₂(L4)] are 1.74, 1.76 and 1.66 BM, respectively. These values correspond to one unpaired electron suggesting a low spin t_{2g}^5 configuration for the ruthenium(III) ion in an octahedral environment.

The solid state EPR spectra of the complexes were recorded in X-band frequencies at room temperature and the 'g' values are given in Table 3. The low spin d^5 configuration is a good probe of molecular structure and bonding since the observed 'g' values are very sensitive to small changes

Table 3EPR data of Ru(III) Schiff base complexes

Complexes	g_x	g_y	g_z	$\left\langle g ight angle ^{st}$
1	2.27	2.27	1.96	2.16
2	2.31	2.31	2.12	2.24
3	2.46	2.46	2.27	2.36
4	2.12	2.12	2.00	2.08
5	2.36	2.36	2.21	2.31
6	2.26	2.26	1.98	2.16
7	2.38	2.38	2.02	2.26
8	2.24	2.24	2.06	2.18
9	2.46	2.46	2.23	2.38
10	2.42	2.42	2.16	2.33
11	2.38	2.38	2.21	2.32
12	2.26	2.26	2.01	2.17
13	2.13	2.13	1.91	2.05
14	2.22	2.22	2.08	2.17
15	2.24	2.24	2.07	2.18
16	2.45	2.45	2.20	2.37

$$\langle g \rangle^* = \left[\frac{1}{3} g_x^2 + \frac{1}{3} g_y^2 + \frac{1}{3} g_z^2 \right]^{1/2}$$

in structure and to metal ligand covalency. The EPR spectra of all the complexes exhibit a characteristic of an axially symmetric system with g_{\perp} around 2.12–2.46 and g_{\parallel} around 1.91–2.27. For an octahedral field with tetragonal distortion $g_x = g_y \neq g_z$ and hence two 'g' values indicate tetragonal distortion in these complexes. A representative spectrum of complex [RuBr₂(PPh₃)₂(L1)] is displayed in Fig. 2. Overall the position of lines and nature of the EPR spectra of the



Fig. 2. EPR spectrum of [RuBr₂(PPh₃)₂(L1)].

^a Charge transfer.

^b $\pi - \pi^{*}$.

^c $n-\pi^*$.

Table 4 Electrochemical data of Ru(III) Schiff base complexes

Complexes Ru ^{III} /Ru ^{IV}			Ru ^{III} /Ru ^{II}					
	$\overline{E_{\rm pa}}$ (V)	$E_{\rm pc}$ (V)	$E_{1/2}$ (V)	$\Delta E_{\rm p}~({\rm mV})$	$\overline{E_{\rm pa}}$ (V)	$E_{\rm pc}$ (V)	$E_{1/2}$ (V)	$\Delta E_{\rm p}~({\rm mV})$
1	0.85	0.93	0.89	80	-0.21	-0.27	-0.24	60
2	0.68	0.61	0.64	70	-0.19	-0.27	-0.23	80
3	0.73	0.64	0.68	90	-0.16	-0.23	-0.19	70
4	0.60	0.53	0.56	70	-0.17	-0.25	-0.21	80
5	0.73	0.65	0.69	80	-0.21	-0.25	-0.25	80
6	0.70	0.64	0.67	60	-0.16	-0.25	-0.20	90
7	0.89	0.83	0.86	60	-0.20	-0.27	-0.23	70
8	0.79	0.68	0.73	110	-0.12	-0.20	-0.16	80
9	0.66	0.72	0.69	60	-0.28	-0.40	-0.34	120
10	0.73	0.79	0.65	70	-0.18	-0.27	-0.22	90
11	0.66	0.78	0.72	120	-0.22	-0.30	-0.26	80
12	0.54	0.61	0.57	70	-0.13	-0.20	-0.16	70
13	0.59	0.52	0.55	70	-0.43	-0.49	-0.46	60
14	0.62	0.56	0.59	60	-0.20	-0.26	-0.23	60
15	0.56	0.48	0.52	80	-0.34	-0.43	-0.38	90
16	0.82	0.73	0.77	90	-0.11	-0.19	-0.15	80

Supporting electrolyte: [NBu₄](ClO₄) (0.05M); concentration of the complex: 0.001 M; scan rate: 100 mV s⁻¹.

complexes are characteristic of low spin ruthenium(III) octahedral complexes [30,38,39].

3.4. Electrochemical study

The redox properties of all the complexes were investigated in acetonitrile solution by cyclic voltammetry and the redox processes are metal centered only (Table 4). Cyclic voltammogram of all the complexes $(1 \times 10^{-3} \text{ M})$ exhibit a reversible oxidation and reversible reduction peaks at the scan rate 100 mV s^{-1} . A representative cyclic votammogram of [RuBr₂(PPh₃)₂(L1)] is shown in Fig. 3. All the complexes showed well-defined waves in the range $(E_{1/2})$ +0.52 to +0.89 V (Ru^{IV}/Ru^{III}) and -0.15 to -0.46 V (Ru^{III}/Ru^{II}) versus Ag/AgCl. The redox processes are reversible with peak-to-peak separation (ΔE_p) values ranging from 60–80 mV corresponding to one-electron process [40,41]. For scan rate 100 mV s⁻¹, the ratio i_p/SR $(i_p = peak current; SR = scan rate)$ was approximately one, the peak separation being independent of the scan rate. This



Fig. 3. Cyclic voltammogram of [RuBr₂(PPh₃)₂(L1)].

indicates that the electron transfer is reversible and the mass transfer is limited. It has been observed that some of the complexes show quasireversible ($\Delta E_{\rm P} = 90-120 \text{ mV}$) redox processes which did not change with change in scan rates, supporting reversibility [42]. The electron donating group (-CH₃) ability of the substituent on the phenyl ring of the Schiff base favored oxidation of Ru^{III} to Ru^{IV} [43].

$$[\operatorname{Ru}^{\operatorname{III}} X_2(\operatorname{EPh}_3)_2(L)] \rightleftharpoons [\operatorname{Ru}^{\operatorname{IV}} X_2(\operatorname{EPh}_3)_2(L)]^+ + e^{-1}$$

There is not much variation due to replacement of chlorides by bromides and triphenylphosphine by arsine. Hence, from the electrochemical data it is clear that the present ligand system is ideally suitable for stabilizing the higher oxidation state of ruthenium ion [30].

4. Catalytic activity

Catalytic oxidation of primary alcohols and secondary alcohol by some of the synthesized ruthenium(III) Schiff base complexes were carried out in CH₂Cl₂ in the presence of NMO and the results are summarized in Table 5. The oxidation was performed at room temperature in CH₂Cl₂ from which water was removed using powdered molecular sieves. All complexes oxidize primary alcohol to the corresponding aldehyde and secondary alcohol to ketone with high yield. The aldehyde or ketone formed after 3 h of reflux were quantified as their 2,4-dinitrophenylhydrazone derivatives and there was no detectable oxidation in the absence of ruthenium complexes. Results of present investigation suggest that the complexes are able to react efficiently with NMO to yield a high valent ruthenium-oxo species [44], capable of oxygen atom transfer to alcohols. This was further supported by spectral changes that occur by addition of NMO to a dichloromethane solution of the ruthenium(III) complexes. The appearance

 Table 5

 Catalytic oxidation of alcohols by ruthenium complexes/NMO

Complex	Complex Substrate		Yield ^a (%)	
1	Benzyl alcohol	А	65.0	
	Cinnamyl alcohol	А	88.4	
	Cyclohexanol	K	24.4	
2	Benzyl alcohol	А	95.5	
	Cinnamyl alcohol	А	98.0	
	Cyclohexanol	K	8.6	
3	Benzyl alcohol	А	61.9	
	Cinnamyl alcohol	А	84.8	
	Cyclohexanol	Κ	22.8	
4	Benzyl alcohol	А	63.0	
	Cinnamyl alcohol	А	79.6	
	Cyclohexanol	К	28.0	
7	Benzyl alcohol	А	61.5	
	Cinnamyl alcohol	А	95.5	
	Cyclohexanol	K	22.2	
8	Benzyl alcohol	А	82.6	
	Cinnamyl alcohol	А	89.3	
	Cyclohexanol	Κ	28.3	
13	Benzyl alcohol	А	90.3	
	Cinnamyl alcohol	А	92.0	
	Cyclohexanol	K	32.8	

A or K = corresponding aldehyde or ketone.

^a Yield based on substrate; alcohol (1 mmol); NMO (3 mmol); catalyst (0.01 mmol).

of the peak at 390 nm is attributed to the formation of high Ru(V)-oxo species which is in conformity with other oxoruthenim(V) complexes [44,45]. Further, support in favor of the formation of such species identified from the IR spectrum of solid mass (obtained by evaporation of resultant solution to dryness), which showed a band at 860 cm⁻¹, characteristic of ruthenium(V)-oxo species [43,44,46].

The relatively higher yield for oxidation of cinnamyl alcohol than benzyl alcohol or cyclohexanol is due to the presence of α -CH unit in cinnamyl alcohol, which is more acidic than benzyl alcohol or cyclohexanol. Unsaturated alcohol like cinnamyl alcohol is selectively oxidized at the alcoholic group with high yield without competing double bond. This is an important characteristic of ruthenium/NMO system. It has been observed that these ruthenium(III) Schiff base complexes have better catalytic efficiency in the case of oxidation of benzyl alcohol, cinnamyl alcohol and cyclohexanol when compared to the earlier report [43,45-47] on similar ruthenium complexes as catalysts in the presence of NMO/t-BuOOH. Hence, it is relevant from the cyclic voltammetric data that the oxidation effected by catalysts is likely to occur via ruthenium higher oxidation states, which is easily accessible through chemical oxidation with co-oxidants like NMO, t-BuOOH, PhIO, etc. [18,47].

5. Antibacterial activity

The in vitro cytotoxicity of ligands and the complexes were screened in vitro in order to evaluate activity against two microbes namely bacteria *Stap. aureus* (209p) and *E.*

Table 6	
Antibacterial data of Ru(III) Schiff base complexes	

Complex	Diameter of inhibition zone (mm)					
	Stap. aureus (209p) (50 µl)	E. Coli ESS (2231) (50 µl)				
HL1	-	_				
1	14	15				
3	14	16				
4	15	17				
HL2	_	_				
6	16	15				
7	18	17				
HL3	_	_				
9	15	15				
11	17	18				
HL4	_	_				
13	11	15				
16	13	17				

- denotes no activity.

coli ESS (2231) at minimum concentration and the results are shown in Table 6. The results indicate that the complexes show more activity and the ligands do not have any activity against same microbes under identical experimental conditions. This would suggest that the chelation could facilitate the ability of a complex to cross a cell membrane [48] and can be explained by Tweedy's chelation theory [49]. Chelation considerably reduces the polarity of the metal ion because of partial sharing of its positive charge with donor groups and possible π -electron delocalization over the whole chelate ring. Such a chelation could enhance the lipophilic character of the central metal atom, which subsequently favors its permeation through the lipid layer of the cell membrane. The variation in the effectiveness of different compounds against different organisms depends either on the impermeability of the cells of the microbes or on differences in ribosome of microbial cells. Though the complexes of this type were found to have potential antibacterial activity against the bacterial microbes, it could not reach the effectiveness of the conventional bacterial control Ampicillin.

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