Available online at www.joac.info

ISSN: 2278-1862

Journal of Applicable Chemistry

2019, 8 (3): 1475-1485

(International Peer Reviewed Journal)

Biochemical Studies on Some New Chelates of Co(II), Ni(II) and Cu(II)

Pravin Prajapati[1]*, Manish Brahmbhatt[1], Jabali Vora[2] and Kuntal Prajapati[1]

1. Sheth M. N. Science College, Hem. North Gujarat University, Patan, INDIA
2. Department of Chemistry, Hem. North Gujarat University, Patan, INDIA

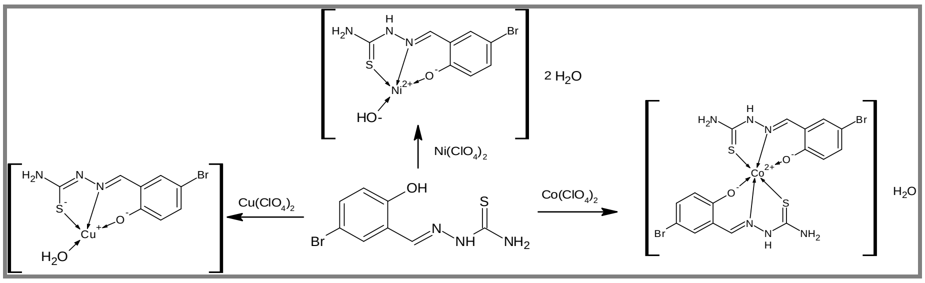
Email: pravinprajapati3690@gmail.com

Accepted on 13th May, 2019

ABSTRACT

Metal chelates of Co(II), Ni(II) and Cu(II) have been synthesized from metal perchlorate and Schiff base (BST) derived from condensation of 5-bromosalicylaldehyde and thiosemicarbazide. Schiff base ligand and metal chelates have been structurally evaluated by elemental analysis, IR, Mass, molar conductance, magnetic susceptibility, UV visible reflectance spectra and Thermogravimetric analysis. All the chelates were studied for catalytic activity. Activation energy of thermal degradation reaction was also evaluated by Broido method. Synthesized Schiff base ligand and chelates were tested for antibacterial activity against two-gram negative bacteria (Escherichia coli, Pseudomonas aeruginosa) and two-gram positive bacteria (Bacillus subtilis, Bacillus cereus)using Ciprofloxacin as the standard.

Graphical Abstract



Keywords: Metal chelates, Schiff base, Antibacterial activity, Catalysis.

INTRODUCTION

Metal chelates of tridentate Schiff base ligands having oxygen, nitrogen and sulphur as donor atoms have been studied extensively in recent years and have become chief interest to coordination chemists due to its varied biological activity [1, 2]. Many biomolecules contain N and O as active sites that play vital role in the coordination of metals. Schiff base ligands with O, N and S donors atoms act as good chelating agents both for transition and non transition metal ions [3]. Transition metal complexes of Schiff base are widely used for industrial purpose as catalyst and also display wide range of biological activities such as antibacterial, antifungal, antiviral, anti-cancer, antimalarial, anti-inflammatory, antiproliferative and antipyretic properties [4-7].

Thiosemicarbazones derived Schiff base are the important class of sulphur donor ligands and are mainly useful for transition metal ions. They show remarkable biological activity which makes them important class of compounds in the pharmaceutical and medicinal fields [8-10].

In present work, synthesis of Co(II), Ni(II) and Cu(II) metal ions chelates with Schiff base are reported and structurally characterized on the basis of analytical, physical and spectral data. The Schiff base and metal chelates have been studied for antibacterial activities. The Schiff base used for this work is shown in figure 1.

MATERIALS AND METHODS

All the chemicals used in the present work were of analytical grade. A stock solution of Co(II), Ni(II) and Cu(II) perchlorates were prepared and standardized by complexometric titration method [11]. Conductivity water was used through the experiments. Microanalysis for carbon, hydrogen, nitrogen and sulphur were carried out using Thermo Finnigan FLASH EA 1112 Series CHN Analyzer.IR spectra of the solid were recorded in KBr pellets with a Shimadzu, IR Affinity 1 S spectrophotometer. For further confirmation by infrared spectroscopy, Far-IR was also recorded with the help of Bruker, 3000 Hyperion Microscope with Vertex 80 FTIR System spectrophotometer. Magnetic moment were determined by Gouy's method at room temperature using Hg[Co(SCN)$_4$] as a calibrant. Thermogravimetric analysis was obtained by using a Perkin-Elmer Diamond Thermogravimetric /Differential Thermal Analyzer. The UV Visible reflectance spectra of the chelates were recorded by using Perkin Elmer lambda 950 UV-VIS-NIR Spectrophotometer. Two-gram positive and two-gram negative bacteria were used to study the biological activity of chelates.

Preparation of Schiff base: A mixture of 2.01 gm 5-Bromo salicylaldehyde (0.01 mol) in sodium carbonate solution and 0.91 gm of thiosemicarbazide (0.01 mol) dissolved in deionized water were refluxed for 2 h [12]. The resulting reaction mixture thus obtained was filtered and acidified by 50 % hydrochloric acid which resulted in precipitation of Schiff base. The precipitated product then filtered off under suction, recrystallized with hot ethanolic solution and dried. The melting point of Schiff base was found to be 232°C.

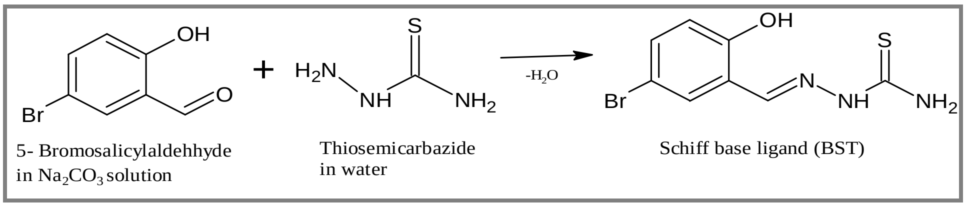


Figure 1. Synthesis scheme for 5-Bromosalicylaldehydethiosemicarbazide Schiff base (BST)

Preparation of metal chelates: Three transition metal chelates of Schiff base ware synthesized using with this procedure. A transition metal perchlorate solution (70 mL, 0.1 M) and the solution of Schiff base (70 mL, 0.1 M) in the ethanol-water solvent were mixed in 1:1 molar ratio. The resulting mixture was refluxed for about 3 h and cooled to room temperature. There was no immediate precipitation. The pH of the reaction mixture was raised up to 5 pH by using alkali solution which resulted in precipitation. The precipitated product thus obtained was washed well with alcohol and water and dried in oven at about 50°C to 60°C temperature [13].

RESULTS AND DISCUSSION

Characterization of Schiff base: The Schiff base was structurally characterized by elemental analysis, IR and mass spectra. The result of elemental analysis shows Schiff base ligand have molecular formula $C_8H_8BrN_3OS$. The results found are in close agreement with those calculated for proposed formula of Schiff base. TLC (ethyl acetate: n-hexane in 3:7 ratio) and melting point was also recorded. Single and separate spot in TLC and sharp melting point suggesting the purity of the synthesized Schiff base.

The mass spectrum of Schiff base ligand is shown in figure 2. Molecular peak M^+ (also base peak) and isotopic peak M+2 of about equal intensity was observed at m/z 273.9 and 275.9. Peak observed at m/z 258.8 corresponds to $C_8H_6BrN_2OS$ fragment and peak observed at m/z 200 is possibly due to C_7H_6BrNO fragment. The IUPAC name of the Schiff base ligand is (2E)-2-(5-bromo-2-hydroxybenzylidene)hydrazine carbothioamide and it is abbreviated as BST.

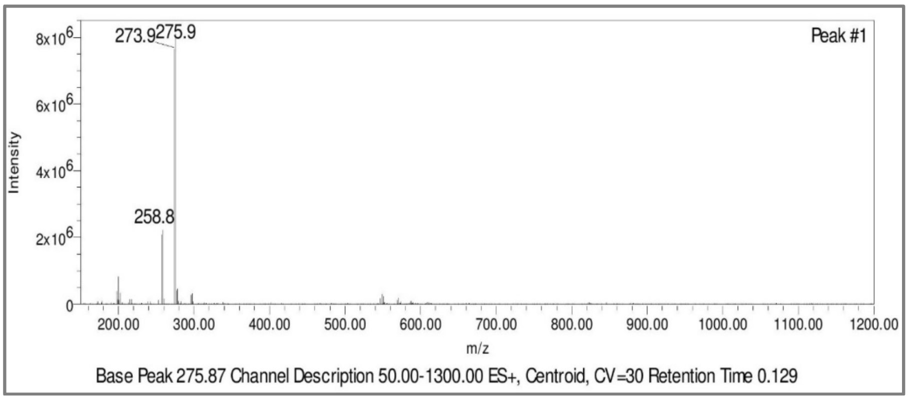


Figure 2. Mass spectrum of 5-Bromosalicylaldehyde thiosemicarbazide Schiff base.

Elemental analysis of metal chelates: The elemental analysis data of metal chelates are shown in table 1. Metal content of chelates were obtained by complexometric titration against standard EDTA solution using appropriate indicator at proper value of pH. The analytical data show that the synthesized chelates proposed to have formula $[CoL_2]\cdot H_2O$, $[NiL(OH)]\cdot 2H_2O$ and $[CuL(H_2O)]$. All the synthesized chelates were found to be soluble in DMF and DMSO but insoluble in other common organic solvents such as methanol, ethanol, acetone, chloroform or in water.

Table 1. Analytical and physical data of Schiff base ligand and its metal chelates

Compound	Colour (Formula weight)	m.p. (°C)	% Found (calculated)					Λ_m Ω^{-1} cm^{2}mol^{-1}
			C	H	N	S	M*	
BST ($C_8H_8BrN_3OS$)	Colourless (274.13)	232	34.647 (35.05)	2.769 (2.94)	15.318 (15.33)	8.837 (11.70)	--	--
Co-BST ($C_{16}H_{16}Br_2CoN_6O_3S_2$)	Dark Brown (623.21)	>300	31.081 (30.84)	2.532 (2.59)	13.145 (13.48)	10.775 (10.29)	8.83 (9.46)	2.674
Ni-BST ($C_8H_{12}BrN_3NiO_4S$)	Red (384.86)	>300	26.385 (24.97)	2.624 (3.14)	11.197 (10.92)	8.261 (8.33)	14.26 (15.25)	0.132
Cu-BST ($C_8H_8BrCuN_3O_2S$)	Dark Brown (353.68)	>300	28.784 (27.17)	2.029 (2.28)	12.081 (11.88)	10.609 (9.07)	17.47 (17.97)	0.864

*Estimation by complexometric titration with EDTA.

Molar conductivities of metal chelates: The molar conductance of the metal chelates was determined using corresponding 1×10^{-3} M solutions in DMSO. The molar conductance of metal chelates was found in the range of 0.132 to 2.674Ω^{-1} cm^2 mol^{-1} suggesting that all the synthesized chelates are non-electrolytic in nature. This is consistent with the fact that molar conductance of nonelectrolytes is below 50 Ω^{-1} cm^2 mol^{-1}in DMSO solution [14].

IR spectra: The IR spectral data with assignment of major peaks of Schiff base ligand and its chelates with Co(II), Ni(II) and Cu(II) are shown in table 2. Binding mode of the Schiff base ligand to metal ions can be studied by comparing IR spectrum of Schiff base and that of metal chelates.

Table 2. Infrared spectral Data for BST and its transition metal chelates

Compound	H_2O	-OH (phenolic)	$-NH_2$	-NH-	C=N	C=S	C-O	M-N	M-O	M-S
BST	--	3163.26	3043.67, 2997.38	3454.51	1606.70	1354.03, 825.53	1209.37	--	--	--
Co- BST	3200	--	3468, 3458.37	3550.95	1602.56	1321.24, 813.96	1199.72	576.65	480.88	365.42
Ni- BST	3550	--	3180.62, 3174.83	3307.92	1597.06	1336.67, 825.53	1192.01	547.11	477.87	317.47
Cu- BST	3018.60	--	3417.86, 3265.49	--	1600.92 (coordinated), 1635.64 (uncoordinated)	1340.53, 810.10	1188.15	574.54	473.65	340.39

The IR spectrum of ligand (BST) shows peak at 3163.26 cm^{-1} assigned to v(OH) phenolic group. The disappearance of this peak in the spectra of chelates suggest deprotonation of -OH (phenolic) group and coordination to metal through deprotonated -OH (phenolic) group. Furthermore, v(C-O) stretching band observed at 1209.37 cm^{-1} in free ligand, appeared in region 1199.72 to 1188.15 cm^{-1}, suggesting coordination by phenolic oxygen atom to the metal ions [15, 16]. This is further supported by peak appeared in the range of 473.65 cm^{-1} to 480.88 cm^{-1} assigned for v(M-O) stretch [17, 18].

The IR spectrum of Schiff base ligand shows strong peak at 1606.70 cm^{-1} which is assigned to the azomethine v(C=N) group vibration. In metal chelates, this band is shifted to lower frequencies in the range of 1602 cm^{-1} to 1597 cm^{-1} [19], indicating coordination of the imine nitrogen atom to the metal ion. This is further confirmed by appearance of IR bands in the region of 547.11cm^{-1} to 576.65 cm^{-1} in the metal chelates assigned to v(M-N) stretch [20, 21].

The peak observed in the Schiff base ligand at 1354.03, 825.53is assigned to v(C=S) stretching and bending mode of vibration [22, 23] and these bands shifted to lower wave number in the chelates indicating coordination of sulfur to metal ions. Also, this coordination is supported by v(M-S) vibration around 365.42 cm^{-1} to 317.47cm^{-1} [24, 25].

In Schiff base ligand and its chelates, two bands observed in the region of 3000 cm^{-1} to 3500 cm^{-1} are assigned for v($-NH_2$) stretch and single peak observed in the range of 3300 cm^{-1} to 3550 cm^{-1} assigned for v(-NH-) stretch. The OH stretching band observed in the spectra of chelates around 3000cm^{-1} to 3500 cm^{-1} is attributed to presence of water of coordination and/or water or hydration.

Thermal analysis: TGA was carried out for chelates by controlling heating rates at 10°C min^{-1} in the range of room temperature to 1000°C by using Perkin-Elmer Diamond Thermogravimetric/ Differential Thermal Analyzer. Thermal analysis is used to examine thermal stability of chelates as well as in elucidation of water content present in chelates as water of coordination and/or as lattice water.

Weight loss below 150°C is due to lattice water and above 150°C is due to coordinated water molecule [26]. TGA data of chelates are shown in table 3. TGA data for Co, Ni and Cu chelates show weight loss of 3.242 % (20.2043 gm mol^{-1}), 12.858 % (49.485 gm mole^{-1}) and 0.548 % (1.9381 gm mole^{-1}) in the temperature range of R.T. to 150°C indicating that cobalt and nickel chelate have considered as one and two lattice water molecules respectively, whereas copper have no lattice water molecules. In the range of 150°C to 250°C, 0.762 % (4.749 gm mole^{-1}), 0.523 % (2.01 gm mole^{-1}) and 5.499 % (19.45 gm mole^{-1}) weight loss were observed for Co(II), Ni(II) and Cu(II) chelates respectively, suggesting copper chelate have one coordinated water molecule whereas cobalt and nickel chelates have no coordinated water molecules.

Table 3. Thermogravimetric analysis of metal chelates

Chelate	RT to 150°C			150°C to 250°		
	% weight loss	gm mole^{-1}	No. of water molecule per chelate molecule (water of crystallization)	% weight loss	gm mole^{-1}	No. of water molecule per chelate molecule (water of coordination)
Co-BST	3.242	20.2043	1	0.762	4.749	0
Ni-BST	12.858	49.485	2	0.523	2.01	0
Cu-BST	0.548	1.9381	0	5.499	19.45	1

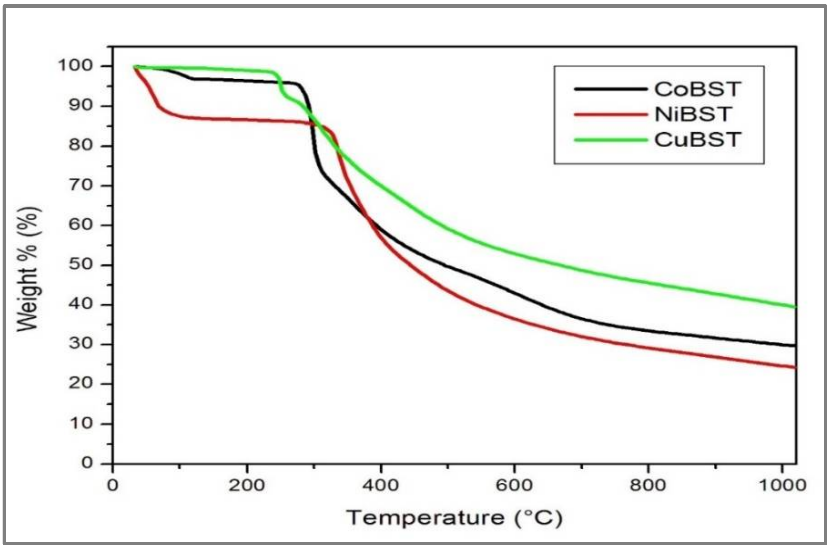


Figure 3. TGA data of Chelates.

Electronic spectra and magnetic properties: Electronic spectra and magnetic moment data are used in elucidation of geometry and coordination number of chelates.

The electronic spectrum of the cobalt chelate shows bands at 14749.26 cm^{-1} and18867.92 cm^{-1} which may be assigned for $^{4}T_{1(g)}$ (F)$\rightarrow{}^{4}A_{2g}$(P) and $^{4}T_{1(g)}$ (F)$\rightarrow{}^{4}T_{1g}$(P) transitions and band observed at 23041.47 cm^{-1} may be due to charge transfer. These transitions, as well as the magnetic moment value are 1.80B.M. suggesting octahedral geometry of the cobalt chelate [27, 28] (Table 4).

Table 4. UV-Visible reflectance Spectra and Magnetic moment Data of the Chelates

Chelate	Absorption λ_{max} (cm^{-1})	Assignment	Magnetic moment μ (B.M.) (Geometry)
Co-BST	14749.26 cm^{-1}	$^{4}T_{1(g)}$ (F)$\rightarrow{}^{4}A_{2g}$(P)	1.80
	18867.92 cm^{-1}	$^{4}T_{1(g)}$ (F)$\rightarrow{}^{4}T_{1g}$(P)	(Octahedral)
	23041.47 cm^{-1}	Charge transfer	
Ni-BST	19305.02 cm^{-1}	$^{1}A_{1(g)}\rightarrow{}^{1}A_{2g}$	0.0
	21276.59 cm^{-1}	$^{1}A_{1(g)}\rightarrow{}^{1}B_{1g}$	(Square planar)
	25839.79 cm^{-1}	Charge transfer	
Cu-BST	16656.71cm^{-1}	$^{2}B_{1g}\rightarrow{}^{2}A_{1g}$	1.68
	21321.96 cm^{-1}	$^{2}B_{1g}\rightarrow{}^{2}E_{1g}$	(Square planar)
	25906.73 cm^{-1}	Charge transfer	

The electronic spectrum of the nickel chelate exhibits bands at 19305.02 cm^{-1}and 21276.59 cm^{-1}that could be assigned for $^{1}A_{1(g)}\rightarrow{}^{1}A_{2g}$ and $^{1}A_{1(g)}\rightarrow{}^{1}B_{1g}$ transitions and band observed at 25839.79 cm^{-1}may be due to charge transfer. These transitions and magnetic moment value is 0.0 B.M. indicating square planar geometry of the nickel chelate [29].

Cu(II) chelate has magnetic moment value 1.68 B.M. and bands observed at 16656.71 cm^{-1} and 21321.96 cm^{-1} which may assigned for $^2B_{1g} \rightarrow {}^2A_{1g}$ and $^2B_{1g} \rightarrow {}^2E_{1g}$ and band observed at 25906.73 cm^{-1} may be due to charge transfer transition. The magnetic moment value and transitions correspond to square planar geometry of copper chelate [30] (Figure 4).

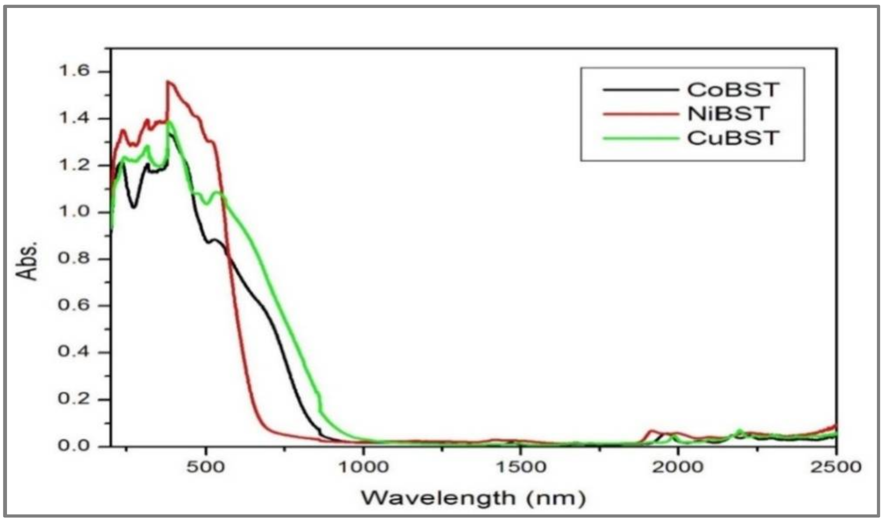


Figure 4. UV visible reflectance spectra of chelates.

The possible geometry of synthesized metal chelates: On the basis of above discussion, cobalt chelate proposed to have octahedral geometry whereas nickel and copper chelates proposed to have square planar geometry. The possible structure of the chelates is shown in figure 5 to 7.

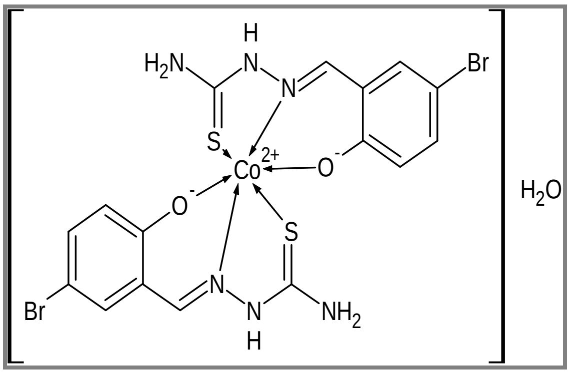


Figure 5. Octahedral geometry for Co(II) Chelate.

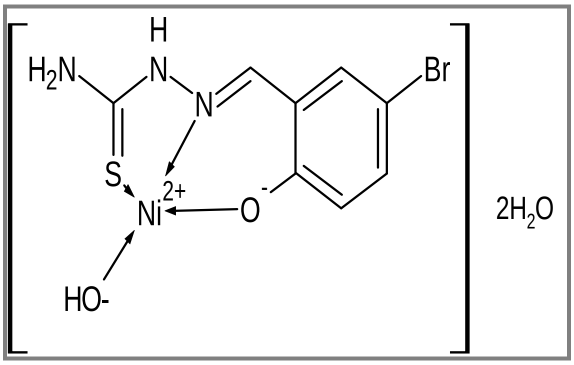


Figure 6. Square planar geometry for Ni(II) Chelate

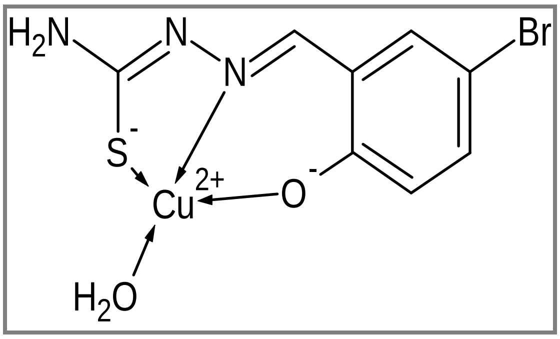


Figure 7. Square planar geometry for Cu(II) Chelate.

Kinetic study: Catalytic effect of chelates was studied by determining the change in the rate of chemical reaction in presence and absence of chelates. For these purpose, three, second order redox reactions, hydrogen peroxide with potassium iodide, potassium bromate with potassium iodide and potassium persulphate with potassium iodide were selected [31].

$$H_2O_2 + 2KI + H_2SO_4 \rightarrow K_2SO_4 + I_2 + 2H_2O$$

$$KBrO_3 + 6KI + 6HCl \rightarrow KBr + 6KCl + 3H_2O + 3I_2$$

$$K_2S_2O_8 + 2KI \rightarrow 2K_2SO_4 + I_2$$

These three redox reactions were carried out with and without addition of chelates. Cobalt chelate increased rate of reaction between potassium bromate with potassium iodide significantly. Nickel chelate is able to increase rate of the reaction between potassium persulphate and potassium iodide to smaller extent only. Copper chelate is able to increase reaction rate of potassium persulphate with potassium iodide and potassium bromate with potassium iodide to considerable extent. In other cases, rate of reaction decreased on addition of chelates.

Table 5. Reaction rates with and without chelates (306 K)

Reactions	$H_2O_2 + KI + H_2SO_4$	$KBrO_3 + KI + HCl$	$K_2S_2O_8 + KI$
k without chelates	2.34078×10^{-4}	7.39218×10^{-4}	3.30786×10^{-5}
k with Co-BST	2.26951×10^{-4}	9.11596×10^{-4}	2.88077×10^{-5}
k with Ni-BST	1.88533×10^{-4}	5.53164×10^{-4}	3.38027×10^{-5}
k with Cu-BST	2.12214×10^{-4}	9.94783×10^{-4}	5.63933×10^{-5}
% Increase in reaction rate at 306 K Co-BST	-3.06	23.32	-12.91
% Increase in reaction rate at 306 K Ni-BST	-19.46	-25.17	2.19
% Increase in reaction rate at 306 K Cu-BST	-9.34	34.57	70.48

Where k denotes rate constant

Catalytic study: 5,5'-diphenylhyntoin is broadly used as anticonvulsant agent and its is medicinally important compound, hence its synthesis is selected for catalytic evaluation. A widely used synthesis of 5, 5'-diphenyl hydantoin was carried out by using literature method [32, 33] in presence and absence of the chelates (Figure 8).

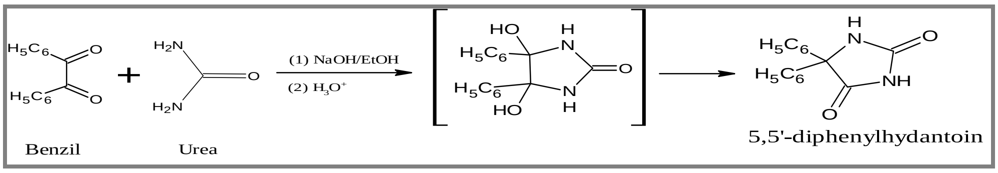


Figure 8. Synthesis scheme for 5, 5'-diphenylhydantoin

This reaction was carried out for 1 h and the yield was 1.268 gm (40.25 %) obtained without catalyst. The same reaction was performed in the presence of 1 mol % catalytic amount of chelates. The % yield and % increase in the yield for catalyzed reaction are shown in table 6. By the use of the catalyst, a marginal increase in reaction rate was observed.

Table 6. % yield of organic reaction at 306K and 1hour reaction time

% yield without chelate (1 h)	% yield with Co-BST (1 h)	% yield with Ni-BST (1 h)	% yield with Cu-BST (1 h)	% Increase of yield in presence of Co-BST	% Increase of yield in presence of Ni-BST	%Increase of yield in presence of Cu-BST
40.25	42.06	41.75	43.24	4.50	3.71	7.41

Activation energy evolution by Broido method: Activation energy and other kinetic parameters can be evaluated from TGA data by Broido method [34]. The equation used to estimate activation energy for thermal degradation reaction is given by,

$$lnln\left(\frac{1}{y}\right) = -\left(\frac{Ea}{R}\right)\left(\frac{1}{T}\right) + constant$$

Where, y denotes fraction of the number of initial molecules not yet decomposed. Plots of lnln(1/y) versus 1000/T for first stage of the thermal degradation of the chelates are shown in figure 9.
The activation energy from the slope of the plot lnln(1/y) versus 1000/T is evaluates as:

$$Ea = -2.303 \times R \times slope$$

Where, R=gas constant

The activation energy value for thermal degradation and temperature range are shown in table 7.

Table 7. Activation energy for thermal degradation

Chelates	Temperature range	Activation energy, Ea $kJmol^{-1}$
Co-BST	37 to 117	102.48 $kJmol^{-1}$
Ni-BST	33 to 68	136.21 $kJmol^{-1}$
Cu-BST	117 to 237	44.52 $kJmol^{-1}$

The activation energy of thermal degradation was found to be 102.48 kJ mol^{-1}, 136.21 kJ mol^{-1} and 44.52 kJ mol^{-1} for cobalt, nickel and copper chelates respectively. The higher value of activation energy reflects the thermal stability of the chelates [35].

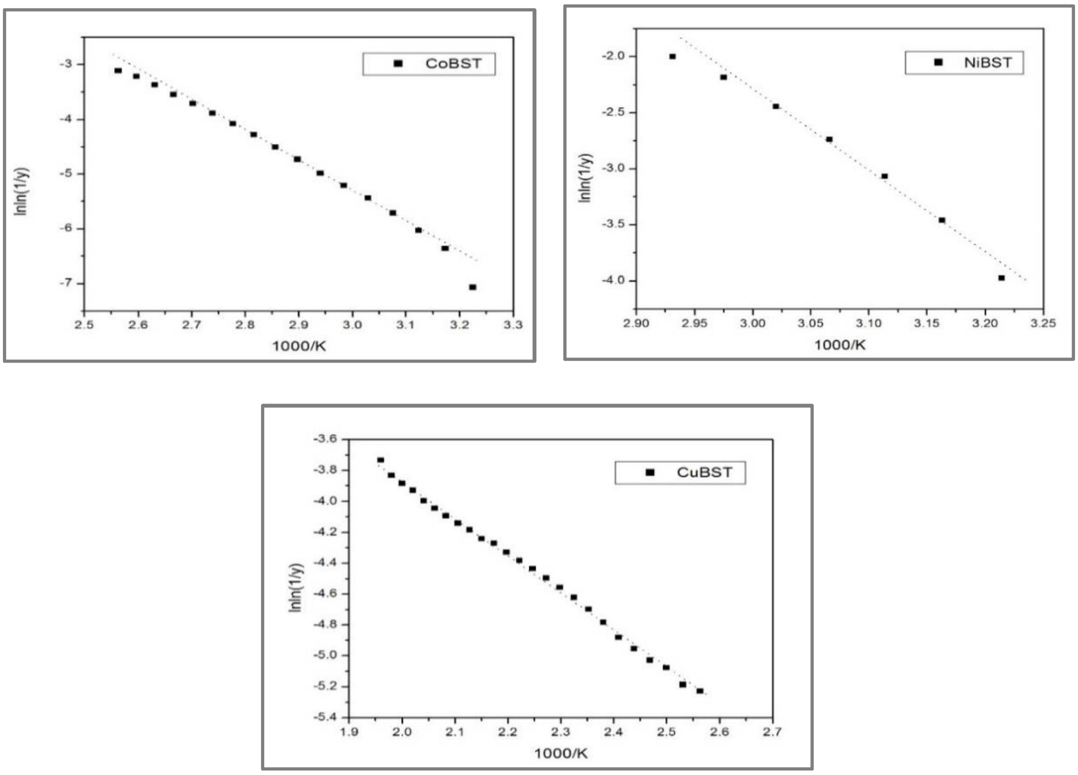


Figure 9. Plot of lnln(1/y) versus 1000/K.

Antibacterial activity: The Schiff base ligand and its chelates with Co(II), Ni(II) and Cu(II) have been screened for their antibacterial activities against two gram negative bacteria (*E. coli, P. aeruginosa*) and with two gram positive bacteria (*B. subtilis, B. cereus*) using Ciprofloxacin as standard. The results of antibacterial activities show that Schiff base ligand was found to be biologically active against all the bacterial stains. Copper chelate shows enhanced activities against all the stains compared to Schiff base ligand. Cobalt chelate shows higher activities against *B. cereus* and *E. coli.* Nickel chelate has shown higher antibacterial activity against E. coli than Schiff base ligand.

Table 8. Antibacterial study of BST Schiff base and chelates.

S. No.	Bacterial species	µg mL^{-1}	BST	Co-BST	Ni-BST	Cu-BST	Ciprofloxacin
1	B. subtilis (G^+)	100	-	-	-	+	+++
		200	+	-	-	+	+++
		300	+	+	-	++	+++
		400	++	++	+	+++	+++
2	B. cereus (G^+)	100	-	-	-	-	+++
		200	-	+	-	+	+++
		300	+	++	+	+	+++
		400	++	++	+	++	+++
3	*E. coli* (G^-)	100	-	-	-	+	+++
		200	-	+	+	++	+++
		300	+	++	++	++	+++
		400	+	+++	++	+++	+++
4	P. aeruginosa(G^-)	100	-	-	-	+	+++
		200	+	+	-	++	+++
		300	+	+	-	+++	+++
		400	+++	++	+	+++	+++

Highly active = +++ (inhibition zone >14 mm); Moderately active = ++ (inhibition zone 11-14 mm); Slightly active = + (inhibition zone 6-10 mm); Inactive = - (inhibition zone <6 mm)

APPLICATION

Cu-BST chelate seems to be a promising catalyst for redox reactions as well as selected condensation reactions and benzil-benzilic acid rearrangements.

CONCLUSION

Chelates of Co(II), Ni(II) and Cu(II) with Schiff base derived from 5-bromosalicylaldehyde and thiosemicarbazide have been prepared from their corresponding metal perchlorate. Schiff base ligand and its chelates were structurally characterized by elemental analysis, infrared spectra, UV-visible spectra, Mass spectra, magnetic moment, molar conductance and TGA. Chelates were also studied for catalytic effect on three well known redox reactions. Copper chelate significantly increased the rate of reaction between potassium bromate with potassium iodide and potassium persulphate with potassium iodide. Cobalt chelate increased the reaction rate between potassium bromate with potassium iodide. Catalytic study for chelates was also carried out for synthesis of diphenylhydantoin. By using Broido method, activation energy of thermal degradation reaction indicates good thermal stability of chelates. Schiff base ligand and its chelates were studied for antibacterial activity against *Bacillus subtilis, Bacillus cereus, Escherichia coli* and *Pseudomonas aeruginosa*. It was observed that on chelation, antibacterial activities were enhanced compared to the ligand. However, the overall antibacterial activity was less at lower concentrations.

REFERENCES

[1]. M. A. Ali, R. Bose, Metal complexes of schiff bases formed by condensation of 2-methoxybenzaldehyde and 2-hydroxybenzaldehyde with S-benzyldithiocarbazate, *Journal of Inorganic and Nuclear Chemistry*, **1977**, 39(2),265-269.

[2]. S. Chandra, S. Bargujar, R. Nirwal, N. Yadav. Synthesis, spectral characterization and biological evaluation of copper (II) and nickel (II) complexes with thiosemicarbazones derived from a bidentate Schiff base, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, **2013**, 106, 91-98.

[3]. M. M. Omar, G. G. Mohamed, A. A. Ibrahim, Spectroscopic characterization of metal complexes of novel Schiff base. Synthesis, thermal and biological activity studies. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, **2009**, 73(2), 358-369.

[4]. A. K. Mishra, N. Manav, N. K. Kaushik, Organotin (IV) complexes of thiohydrazones: synthesis, characterization and antifungal study, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, **2005**, 61(13-14), 3097-3101.

[5]. C. Ramalingan, S. Balasubramanian, S. Kabilan, and M. Vasudevan, Synthesis and Study of Antibacterial and Antifungal Activities of Novel 1-[2-(Benzoxazol-2-Yl) Ethoxy]-2, 6-Diarylpiperidin-4-Ones, *European Journal of Medicinal Chemistry*, **2004**, 39 (6), 527–533.

[6]. A. M. Abu-Dief, I. M. Mohamed, A review on versatile applications of transition metal complexes incorporating Schiff bases, *Beni-suef university journal of basic and applied sciences*, **2015**, 4(2), 119-133.

[7]. K. C. Gupta, A. K. Sutar, Catalytic activities of Schiff base transition metal complexes, *Coordination Chemistry Reviews*, **2008**, 252(12-14), 1420-1450.

[8]. A. A. Al-Amiery, A. A. Kadhum, A. B. Mohamad, Antifungal and antioxidant activities of pyrrolidone thiosemicarbazone complexes, *Bioinorganic Chemistry and Applications*, **2012**, 1-6.

[9]. K. S. Abou-Melha, H. Faruk, Bimetallic complexes of Schiff base bis-[4-hydroxycuomarin-3-yl]-1 N, 5 N-thiocarbohydrazone as a potentially dibasic pentadentate ligand. Synthesis, spectral, and antimicrobial properties, *Journal of the Iranian Chemical Society*, **2008**, 5(1), 122-134.

[10]. K. S. Jacob, G. Parameswaran, Corrosion inhibition of mild steel in hydrochloric acid solution by Schiff base furoin thiosemicarbazone, *Corrosion Science*, **2010**, 52(1), 224-228.

[11]. A. I. Vogel, Quantitative inorganic analysis, theory and practice. London: Longmann, Green and Co. **1961**, 412.

[12]. J. Joseph, N. L. Mary, R.Sidambaram, Synthesis, characterization, and antibacterial activity of the Schiff bases derived from thiosemicarbazide, Salicylaldehyde, 5-bromosalicylaldehyde and their copper (II) and nickel (II) complexes. *Synthesis and Reactivity in Inorganic, Metal-Organic, and Nano-Metal Chemistry*, **2010**, 40(10), 930-933.

[13]. P. H. Modh, J. J. Vora, Synthesis, spectral, thermal, antimicrobial and catalytic activity of Zn^{2+} and Cd^{2+} chelates with valsartan, *Int. J Pharma Bio Sci*, **2014**, 5(2), 383–389.

[14]. W. J. Geary, The use of conductivity measurements in organic solvents for the characterisation of coordination compounds, *Coordination Chemistry Reviews*, **1971**, 7(1), 81-122.

[15]. A. Çukurovali, I. Yilmaz, H. Özmen, M.Ahmedzade, Cobalt (II), copper (II), nickel (II) and zinc (II) complexes of two novel Schiff base ligands and their antimicrobial activity, *Transition metal chemistry*, **2002**, 27(2), 171-176.

[16]. M. S. Refat, I. M. El-Deen, Z. M. Anwer, S. El-Ghol, Spectroscopic studies and biological evaluation of some transition metal complexes of Schiff-base ligands derived from 5-arylazo-salicylaldehyde and thiosemicarbazide, *Journal of Coordination Chemistry*, **2009**, 62(10), 1709-1718.

[17]. Temel H, İlhan S, Şekerci M, Ziyadanoğullari R. The synthesis and spectral characterization of new Cu (II), Ni (II), Co (III), and Zn (II) complexes with Schiff base. Spectroscopy letters, **2002** Jun 5;35(2):219-28.

[18]. Z. H. El-Wahab, M. R. El-Sarrag, Derivatives of phosphate Schiff base transition metal complexes: synthesis, studies and biological activity, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, **2004**, 60(1-2), 271-277.

[19]. N. Raman, A. Selvan, P. Manisankar, Spectral, magnetic, biocidal screening, DNA binding and photocleavage studies of mononuclear Cu (II) and Zn (II) metal complexes of tricoordinate

heterocyclic Schiff base ligands of pyrazolone and semicarbazide/thiosemicarbazide based derivatives, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy,* **2010**, 76(2), 161-173.

[20]. K. Mounika, A. Pragathi, C. Gyanakumari, Synthesis characterization and biological activity of a Schiff base derived from 3-ethoxy salicylaldehyde and 2-amino benzoic acid and its transition metal complexes, *Journal of Scientific Research*, **2010**, 2(3), 513-524

[21]. S. E. Etaiw, D. M. El-Aziz, E. H. El-Zaher, E. A. Ali, Synthesis, spectral, antimicrobial and antitumor assessment of Schiff base derived from 2-aminobenzothiazole and its transition metal complexes, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, **2011**, 79(5), 1331-1337.

[22]. J. G. Mahetar, M. J. Mamtora, M. B. Gondaliya, R. B. Manawar, M. K. Shah,Synthesis, characterization and antimicrobial activity of transition metal complexes of thiosemicarbazone bearing vanillin moiety,*World J Pharm Res*., **2014**, 3(3), 4383–4392.

[23]. P. Bindu, M. R.Kurup, T. R. Satyakeerty,Epr, cyclic voltammetric and biological activities of copper (II) complexes of salicylaldehyde N (4)-substituted thiosemicarbazone and heterocyclic bases,*Polyhedron,* **1998**, 18(3-4), 321-331.

[24]. K. S. Melha, In-vitro antibacterial, antifungal activity of some transition metal complexes of thiosemicarbazone Schiff base (HL) derived from N4-(7′-chloroquinolin-4′-ylamino) thiosemicarbazide, *Journal of enzyme inhibition and medicinal chemistry*, **2008**, 23(4), 493-503.

[25]. M. E. Zayed, Microwave-Assisted Synthesis and Spectral Characterization of Biological Activity Heterocyclic Thiosemicarbazone and Its Organometallic Derivatives, *Journal of Heterocyclic Chemistry*, **2019**, 56(1), 32-37.

[26]. A. V. Nikolaev,V. A. Logvinenko, L. T. Myachina, Thermal Analysis; Academic Press: New York, **1969**, 779.

[27]. C. Natarajan, C. D. Sheela, P. R. Athappan, Synthesis and study of cobalt (II), nickel (II), copper (II) and zinc (II) complexes of 2-formyl-and 2-acetyl-cyclohexanones, *Indian J Chem.,* **1990**, 29A, 569-572.

[28]. A. B. P. Lever. Inorganic electronic spectroscopy. 1st ed. Amsterdam : Elsevier; **1968**. 320.

[29]. N. Raman, A. Kulandaisamy, K. Jeyasubramanian, Synthesis, spectral, redox and biological studies of some Schiff base copper (II), nickel (II), cobalt (II), manganese (II), zinc (II) and oxovanadium (II) complexes derived from 1-phenyl-2, 3-dimethyl-4 (4-iminopentan-2-one) pyrazol-5-one and 2-aminophenol/2-aminothiophenol, *Indian J Chem*. **2002**, 41A, 942–949.

[30]. S. S. Konstantinovic, B. C. Radovanovic, Z. Cakic, V. Vasic, Synthesis and characterization of Co (II), Ni (II), Cu (II) and Zn (II) complexes with 3-salicylidenehydrazono-2-indolinone, *Journalserbian Chemical Ssociety*, **2003**, 68(8-9), 641-647.

[31]. J. B. Yadav, Advanced Practical Physical Chemisty, Krishna Prakashan Media, **2006**, 63-85.

[32]. B. S. Furniss, Vogel's textbook of practical organic chemistry, Pearson Education India, **1989**, 1153.

[33]. M. C. Pankaskie, L. Small, The synthesis of 5, 5'-diphenylhydantoin: A novel benzil-benzilic acid rearrangement, *Journal of Chemical Education*, **1986**, 63(7), 650

[34]. A. Broido, A simple, sensitive graphical method of treating thermogravimetric analysis data, *Journal of Polymer Science Part A-2: Polymer Physics*, 1969, 7(10), 1761-1773.

[35]. K. R. Patel, Dhara Patel, A.Patel, Study of Activation Energy and Thermodynamic Parameters from TGA of Some Synthesized Metal Complexes, *Indian J Appl Res.*, **2013**, 3(4), 410–412.