

Synthesis and characterization of new benzothiazole-derived ligand and its complexes with some transitional metal ions with evaluation of their biological activities

*Wesam Abed AL Hassan Alhaidry, ** Hayder Obaid Jamel

*Department of chemistry, College of education/ University of Al- Qadisiyah, Iraq.

** Department of pharmaceutical chemistry, College of Pharmacy/ University of Al- Qadisiyah, Iraq.

Abstract

Background: In the current years, there has been significant interest in the chemistry of transitional metal complexes of Schiff's bases. The latter possess pharmacological activities such as antimicrobial, antimicrobial, antitubercular, antitubercular, antiviral and antimalarial. The aim of current study was to prepare a new ligand [3-{4-[4-(Benzothiazol-2-ylamino)-benzyl]-phenylimino}-butan-2-oneoxime] (BTBPBO) from the reaction of 2-mercaptobenzothiazole with 4,4-diaanilinemethane, then the product of this step reacted with diacetyl monoxime.

Methods: The complexes in question were prepared from reaction of ligand with transitional metal salts [Co(II), Cu(II), Ag(I), Cd(II) and Hg(II)] in the ethanol as solvent. In addition, the synthesized ligand (BTBPBO) and its complexes were characterized by using the physical and spectral methods to determine the stereo geometry and the structure of ligand and its complexes.

Results and Conclusion: the results showed that the stereo geometries of the complexes are tetrahedral except Co (II), Cu (II) complexes were octahedral. The ligand (BTBPBO) and its metal complexes exhibited good antibacterial activities.

Key words: Schiff's bases, ligand, transitional metals, stereochemistry, antibacterial activity, spectral methods.

INTRODUCTION

In current years, there has been significant interest in the chemistry of transitional metal complexes of Schiff's bases due to their activities as Fluorimetric Analytical Reagents, intermediates for synthesis of heterocyclic antimicrobial agents and anti-oxidant products^[1,2].

Schiff's base ligands have significant importance in chemistry, especially in the development of Schiff's base complexes, because they are possibly capable of forming stable complexes with metal ions and many of them also show excellent catalytic activity in different reactions at high temperature and in the presence of moisture^[3].

A Schiff base (also known as imine or azomethine) is a nitrogen analogue of an aldehyde or ketone in which the carbonyl group (CO) has been replaced by an imine or azomethine group^[4]. They have been found to possess pharmacological activities such as antimicrobial, antitubercular, antiviral and antimalarial^[5,6].

Benzothiazole is a heterocyclic compound, with molecular formula (C₇H₅NS), weak base and is one of the biologically active heterocyclic compounds formed by the benzene ring fused with 4, 5 positions of thiazole rings. Benzothiazole Schiff's bases have a wide variety of applications in analytical, biological, inorganic, medicinal and pharmaceutical fields due to their biological activities like antioxidant, antifungal, anti-inflammatory, antimicrobial, anticancer and cytotoxic activity^[7-10].

The aim of current study was to prepare a new ligand (BTBPBO), derived from benzothiazole, and its compounds with divalent transitional metal ions [Co(II), Cu(II), Ag(I), Cd(II), and Hg(II)] and characterizing them by spectra and physical methods with evaluation of their biological activities.

MATERIALS AND METHODS

Chemicals

All chemicals are provided by B.D.H, Sigma-Aldrich, GCC companies.

Measurements

FTIR Spectra in the range of 400-4000 cm⁻¹ were recorded using FTIR 8400S Shimadzu Spectrophotometer (Japan), while ¹H, ¹³C-NMR spectra of the ligand were recorded using Bruker model Ultrashild 300 MHz NMR. The solvent was DMSO-d₆ and the internal reference TMS. The electronic spectra were measured on Shimadzu UV-Vis. model 1650PC in the range of 200-1000

nm at room temperature using absolute ethanol as solvent. The molar conductance measurements were obtained from device of conductivity meter ER 214 in absolute ethanol solvent and concentration (1x10⁻³M) at room temperature. Melting points of all compounds were determined by the Stuart melting point, Balances-Magnetic Susceptibility, Model MSB-Mk-1, was used to determine magnetic moments effect for complexes. Flame atomic-absorption spectrophotometer, Shimadzu AA-6300, was used to determine metal percentage in the complexes. The percentages of elements in the ligand and its complexes were measured using elemental analysis and recorded on instrument type EA-99.mth.

Preparation of 4-(4-Amino-benzyl)-phenyl-benzothiazol-2-yl-amine (compound -A)

A solution of 1.67g (10 mmol) of 2-mercaptobenzothiazole dissolved in 25ml of absolute ethanol was added to 4,4-dianiline methane solution of 1.98g (10 mmol) and dissolved in 25ml of absolute ethanol with continuous stirring. The mixture was refluxed for 4h. The precipitate was collected and filtered after cooled at room temperature. The solid product was recrystallized from ethanol and dried (M.P= 123-125 °C, yield% = 74 %).

Synthesis of the 3-{4-[4-(Benzothiazol-2-ylamino)-benzyl]-phenylimino}-butan-2-one oxime (BTBPBO) ligand

Diacetyl monoxime (1.01 g; 10 mole) was dissolved in 25ml of absolute ethanol, and 2-3 drops of conc. HCl were added to this solution. A solution of 3.31g (10mmol) of ([4-(4-Amino-benzyl)-phenyl]-benzothiazol-2-yl-amine) in 25ml ethanol and added to the above solution, refluxed for 4h, cooled and the crystals obtained were separated by filtration and recrystallized from ethanol. The precipitate was collected after dry (M.P.= 143-145 °C) (Yield% = 83%).

Preparation of [Co (II), Cu (II), Ag (I), Cd (II), and Hg (II)] complexes

A solution of 0.415g (1mmole) of (BTBPBO) ligand in 15ml of ethanol added to 1mmole of the transition metal chloride solution in 5ml absolute ethanol (0.237gm, 0.171gm, 0.169gm, 0.219gm, 0.271gm). Then, the mixture was refluxed with stirring for 2h, cooled, filtrated, dried and recrystallized by using absolute ethanol to obtain pure complexes. Table (1) showed elemental analysis and some physical properties of the ligand (BTBPBO) and its complexes.

Antibacterial activity

All the newly synthesized compounds were evaluated for *in vitro* antibacterial activity against gram positive (*Staphylococcus aureus*) and gram negative (*Escherichia coli*, *Proteus vulgaris*, *Pseudomonas aeruginosa*) bacteria. The test microorganisms were obtained from College of Biotechnology at AL-Qadisiyah University. All the newly synthesized compounds were weighed and dissolved in dimethylsulphoxide (DMSO) to prepare stock solution of 1000 microgram/milliliter ($\mu\text{g/mL}$) then diluted to prepare other concentration 250 and 500 $\mu\text{g/mL}$ by disc diffusion method^[18] using Mueller-Hinton agar (MH) (Difco, Detroit, MI) was employed as culture media. A volume of 100 μL of compound solution prepared in DMSO (1%) was added in the cup under aseptic conditions with the help of micropipette. A volume of 100 μL of DMSO placed in one of the cups as a blank (negative control) and After 24-48 h of incubation at 37 °C, the zones of inhibition were measured in mm. The activity was compared with a known antibiotic, Gentamycin .

RESULTS AND DISCUSSION

A new ligand 3-{4-[4-(Benzothiazol-2-ylamino)-benzyl]-phenylimino}-butan-2-one oxime (BTBPBO) was prepared by reaction of 2-mercaptobenzothiazole with 4,4-diaanilinmethane, then the product reacted with diacetyl monoxime. The complexes for this ligand were prepared from reaction metals chlorides of [Co (II), Cu (II), Ag (I), Cd (II), and Hg (II)] with (BTBPBO) ligand in ethanol as solvent. This ligand and its complexes were soluble in ethanol, methanol and DMSO. The molar ratio method was used to determine the metal to ligand ratio and showed that this ratio was (1:1). The physical properties and elemental analysis are shown in Table (1).

¹H and ¹³C-NMR spectra of the ligand (BTBPBO)

The ¹H- NMR spectrum of the ligand (BTBPBO) were recorded using DMSO-d₆ as a solvent and TMS as an internal reference at room temperature. The spectrum showed two singlet signals concentrated at (S, δ = 12.367ppm, 1H) and (S, δ = 10.717ppm, 1H) which were due to two protons of hydroxyl of oxime group (-C=N-OH) and amine group (-NH), respectively^[11,12]. There were also multiple signals at the range (M, δ = 7.683-7.709 ppm , 4H) of the benzothiazole ring protons^[13]. Multiple signals were observed at (M, δ = 7.254 -7.396 ppm, 8H) due to the protons of the two phenyl rings^[14]. The singlet signal located at (S, δ = 3.974 ppm , 2H) was due to the protons of the methylene group^[15], whereas the appearance of two singlet signals at (S, δ = 2.297ppm , 3H) and (S, δ = 1.812ppm , 3H) indicated that there are protons of two methyl groups^[16].

A ¹³C-NMR spectrum of free ligand (BTBPBO), which was recorded using DMSO-d₆ as a solvent and TMS as an internal reference at room temperature, showed several signals at the ranges (120.825 – 172.295 ppm), related to carbon atoms that belong to the benzothiazole ring^[17]. The observed signals at (123.374 – 133.949 ppm) were due to the carbon atoms of the two phenyl rings^[18]. The methylene group (-CH₂-) showed a signal at (40.136ppm), also the two methyl groups (-CH₃) showed two signals at (17.113, 26.970 ppm)^[19], while the two signals at (153.190 ,156.659 ppm) were referred to the carbon atoms of the azomethine-oxime (-C=N , -C=N-OH)^[20].

Infra-red spectra

The Infra-red spectrum of the ligand (BTBPBO)

The FTIR spectra were measured using the Shimadzu 8400S and KBR disks. The ligand spectrum showed the disappearance of the N-H group of the primary amine at (3325 and 3417 cm⁻¹) and the appearance of a new band at 1635cm⁻¹ which was due to the frequency of the azomethine group (C=N)⁽²¹⁾. The bands of (OH),(NH) groups^[22] is observed at the wave number (3309, 3186 cm⁻¹), respectively, while the bands at 3039 and 3072cm⁻¹ and at

833, 2893 and 2962cm⁻¹ were attributed to ν (C-H) aromatic and aliphatic^[23], while (C=Nimine), (C=Noxime) and (C=Nbenzothiazole ring) gave bands at 1635, 1586 and 1558cm⁻¹^[24,25]. The bands of (C=C aromatic) group^[26] were concentrated at 1496 and 1537cm⁻¹.

The Infra-red spectra of the complexes

The spectra of the prepared complexes showed a shift in the frequencies of some groups in the free ligand spectrum compared to the spectra of the complexes at lower frequencies than in the free ligand. This is a strong evidence of consistency between ligand and transitional metal ions where complexes' spectra exhibited an occurrence shifted for frequency of (C = Nimine), (C = Noxime) groups by (15-23 cm⁻¹) and (11-28 cm⁻¹) toward lower frequencies compared with their frequency in the free ligand spectrum^[27]. As such, the frequency of the azomethine group (C = N) of benzothiazole ring^[28] was reduced by about (6-14 cm⁻¹) while NH group of the secondary amine^[29] was also shifted to the lower frequencies compared to the free ligand spectrum by about (14-27cm⁻¹). Another evidence of coordination and complexes formation is the appearance of new bands in complexes spectra at the region (418-512 cm⁻¹) which were due to the stretching vibration of the ν (M-N)^[30]. In addition, the new and broad bands at (3417, 3559, 3525 cm⁻¹) indicating hydroxyl group of hydrate water molecules were shown in the cobalt (II), copper (II) and cadmium (II) complexes, respectively^[31].

Electronic spectra

The electronic spectra of the ligand and all of its complexes were obtained in ethanol as solvent at room temperature and (1x10⁻⁵ and 1x10⁻³ M) concentration. The (BTBPBO) ligand spectrum showed peaks at 202 nm (49504 cm⁻¹) and 238 nm (43103 cm⁻¹) which were due to the $\pi \rightarrow \pi^*$ transition of the phenyl and benzothiazole rings. The peak at 323 nm (30959 cm⁻¹) refers to the $n \rightarrow \pi^*$ transition of azomethine groups^[32].

The Co(II) complex spectrum showed peak at 335 nm (29850 cm⁻¹) referred to charge transfer while the absorption peaks at 572 nm (17482 cm⁻¹), 622 nm (16077 cm⁻¹), 656nm (15243cm⁻¹), indicated to (⁴T_{1g} (F) \rightarrow ⁴A_{2g} (F) transition while the other two peaks referred to the transitions (⁴T_{1g} (F) \rightarrow ⁴T_{1g} (P) and ⁴T_{1g} (F) \rightarrow ⁴T_{2g} (F), respectively^[33]. These transitions referred to the octahedral geometry around the metallic ions.

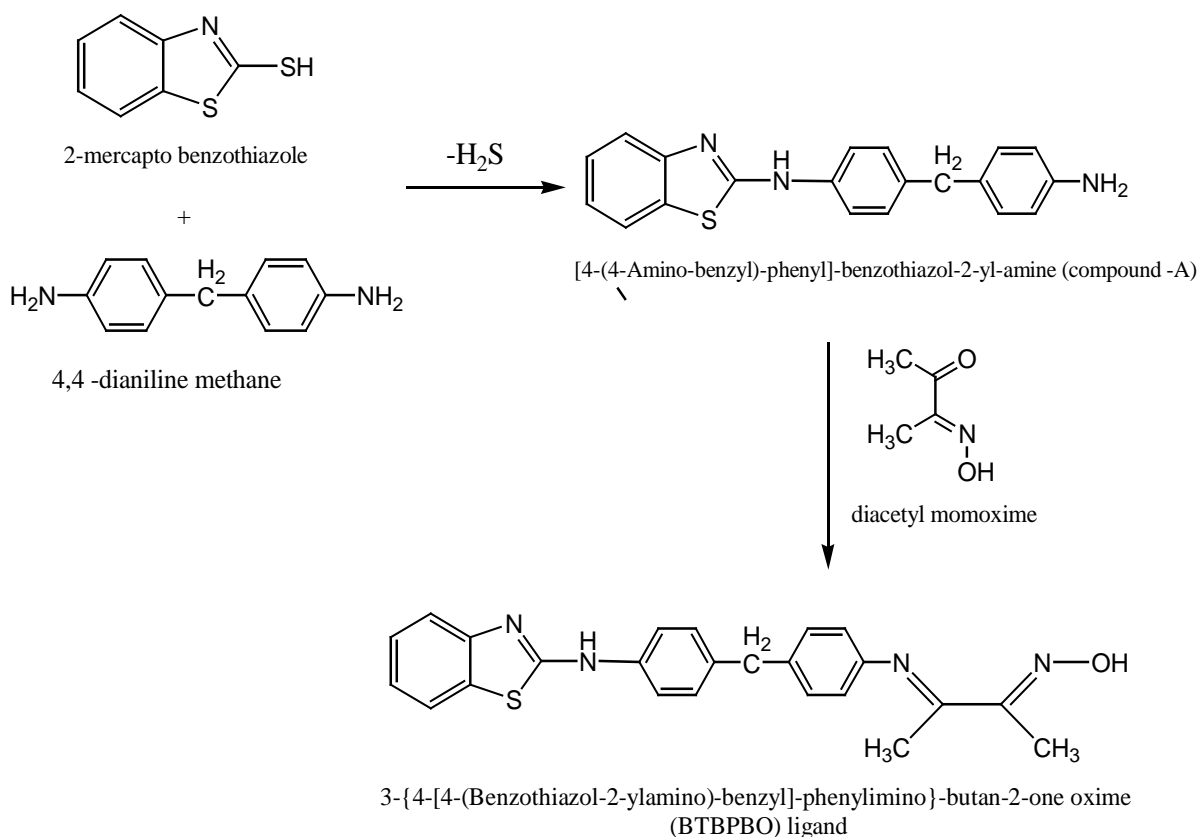
A Cu(II) complex spectrum appeared absorption peak concentrated at 285nm (35087cm⁻¹) which belonged to charge transfer. The absorption peak at 624nm (16025cm⁻¹) which is attributed to the transition ²E_g \rightarrow ²T_{2g} which referred to distorted octahedral copper complexes^[33].

The electronic spectra of Ag(I), Cd(II) and Hg(II) were not important in determining the complex structure due to absence of d-d transitions in their spectra. The latter because the (d) orbitals were completely occupied in metal ions.

The above complex showed several peaks at 405, 409, 393 (24691, 24449, 25445 cm⁻¹). It referred to the charge transfer of the type (metal-ligand)^[34].

Magnetic moment measurements

The values of the magnetic moment of the prepared complexes were measured at the laboratory temperature by using the Freaday method .The effective magnetic (μ_{eff}) values of the complexes are presented in Table (4). The magnetic effective moment of the Co(II) complex was 3.84 B.M. which corresponds to octahedral geometry. In addition, the magnetic moment of Cu(II) complex was 1.72B.M. which corresponds to octahedral geometry around Cu(II) ion while the magnetic moments of Ag(I), Cd(II) and Hg(II) complexes were zero due to the saturation of their orbitals. As a result, these complexes are diamagnetic with tetrahedral geometry^[33,34].



Scheme 1 Synthesis of the 3-{4-[4-(Benzothiazol-2-ylamino)-benzyl]-phenylimino}-butan-2-one oxime (BTBPBO) ligand

Table 1 Elemental analysis and some physical properties of the ligand (BTBPBO) and its metal complexes

No.	Molecular formula	M.wt (gm/mole)	Color	M.P(C°)	Yield (%)	Found (Calc.)%				
						C	H	N	S	M
1	Ligand(BTBPBO)	414.52	Pale -Yellow	143-145	83	69.92 (69.54)	5.45 (5.35)	14.14 (13.52)	7.56 (7.74)	—
2	[Co(BTBPBO)Cl ₂]. H ₂ O	562.38	Pale -Green	156-158	74	51.98 (51.26)	4.43 (4.30)	10.37 (9.96)	5.23 (5.70)	10.72 (10.48)
3	[Cu(BTBPBO)Cl ₂]. H ₂ O	566.99	Dark -Brown	163-165	78	51.19 (50.84)	4.34 (4.27)	10.23 (9.88)	5.45 (5.66)	11.46 (11.21)
4	[Ag(BTBPBO)] NO ₃	584.40	Yellow	167-169	81	50.27 (49.33)	3.92 (3.79)	12.34 (11.98)	5.23 (5.49)	18.73 (18.46)

Table 2 The ¹H-NMR and ¹³C-NMR spectral data of the synthesized ligands (BTBPBO)

¹³ C-NMR		¹ H-NMR	
Assignment	Signals (ppm)	Assignment	Signals (ppm)
(C ₁ -C ₇) Benzothiazole ring	120.825 - 172.295	O-H(oxime)	S, δ= 12.367ppm , 1H
Phenyl rings	(C ₈ -C ₁₃)	N-H(2°amine)	S, δ= 10.717ppm , 1H
	(C ₁₅ -C ₂₀)		
(C ₁₄) Methylene group	40.136	C-H(Benzothiazole ring)	M, δ= 7.683-7.709 ppm , 4H
(C ₂₁ , C ₂₄) Methyl group	17.113 26.970	C-H(Phenyl ring)	M, δ= 7.254 -7.396 ppm , 8H
(C ₂₂ , C ₂₃)(-C=N-)(C=N-OH).	156.659 153.192	C-H(methylene group)	S, δ= 3.974 ppm , 2H
		C-H2 (methyl groups)	S, δ= 2.297ppm , 3H S, δ= 1.812ppm , 3H

Table 3 The important infrared spectral bands for the synthesized ligand (BTBPBO) and its complexes

Compounds	$\nu(\text{O-H})$ $\nu(\text{N-H})$	$\nu(\text{C-H})$ Aromatic	$\nu(\text{C-H})$ Aliphatic	$\nu(\text{C=N})$ Imine	$\nu(\text{C=N})$ Oxime	$\nu(\text{C=N})$ Benzothiazole Ring	$\nu(\text{C=C})$ Aromatic	$\nu(\text{M-N})$	Other Bands
(BTBPBO)	3309 3186	3078 3039	2962 2893 2831	1635	1596	1566	1527 1496	—	—
[Co(BTBPBO)Cl ₂].H ₂ O	3318 3159	3062 3039	2962 2893 2831	1620	1580	1560	1523 1496	424 462 486 512	3525 (O-H) of water molecules
[Cu(BTBPBO)Cl ₂].H ₂ O	3321 3163	3055 3016	2916	1612	1568	1552	1527 1496	418 423 468 484	3559 (O-H) of water molecules
[Ag(BTBPBO)] NO ₃	3331 3172	3084 3016	2900	1620	1585	1558	1542 1504	426 440 457 486	—
[Cd(BTBPBO)] Cl ₂ .H ₂ O	3317 3159	3062 3039	2962 2893 2839	1612	1583	1556	1542 1496	428 462 480 498	3417 (O-H) of water molecules
[Hg(BTBPBO)] Cl ₂	3327 3172	3064 3031	2900 2839	1612	1573	1558	1538 1504	421 442 460 486	—

Table 4 Electronic spectra, Magnetic Moments and Molar conductivity of the ligand (BTBPBO) and its metal complexes

Geometry	Λ ohm ⁻¹ .cm ² . mole ⁻¹	μ_{eff} (B.M)	Transitions	ν (cm ⁻¹)	λ (nm)	Compounds
—	—	—	$\pi-\pi^*$ $\pi-\pi^*$ $n-\pi^*$	49504 43103 30959	202 238 323	(BTBPBO)
Octahedral	17.5	3.84 (Para.)	Charge transfer $^4T_{1g} \rightarrow ^4A_{2g}$ (F) $^4T_{1g} \rightarrow ^4T_{1g}$ (P) $^4T_{1g} \rightarrow ^4T_{2g}$ (F)	29850 17482 16077 15243	335 572 622 656	[Co(BTBPBO)Cl ₂].H ₂ O
Octahedral	14.3	1.72 (Para.)	Charge transfer $^2E_g \rightarrow ^2T_{2g}$	35087 16025	285 624	[Cu(BTBPBO)Cl ₂].H ₂ O
Tetrahedral	39.4	0.00 (Dia.)	Charge transfer(MLCT)	24691	405	[Ag(BTBPBO)] NO ₃
Tetrahedral	79.4	0.00 (Dia.)	Charge transfer(MLCT)	24449	409	[Cd(BTBPBO)] Cl ₂ .H ₂ O
Tetrahedral	73.9	0.00 (Dia.)	Charge transfer(MLCT)	25445	393	[Hg(BTBPBO)] Cl ₂

Table 5 Biological activity data (zone of inhibition in mm) of ligand (BTBPBO) and its metal complexes

Compounds	Corresponding effect on microorganisms							
	<i>S. aureus</i>		<i>P. vulgaris</i>		Pseudo		<i>Escherichia coli</i>	
	500 gm	250 gm	500 gm	250 gm	500 gm	250 gm	500 gm	250 gm
)BTBPBO(Ligand	22.5	18.5	14	9.5	15	11.5	10	8
[Co(BTBPBO)Cl ₂].H ₂ O	10	7.5	14.5	11.5	11.5	8.5	13.5	11
[Cu(BTBPBO)Cl ₂].H ₂ O	13	8	10.5	7.5	25.5	20.5	10.5	8
[Ag(BTBPBO)] NO ₃	11	8	25.5	21	15.5	12.5	10	0
[Cd(BTBPBO)] Cl ₂ .H ₂ O	18	13	13	8	11	7.5	8.5	0
[Hg(BTBPBO)] Cl ₂	30.5	15	25.5	20	25	19.5	29	15
G	19		20		15		17	

G: Gentamycin

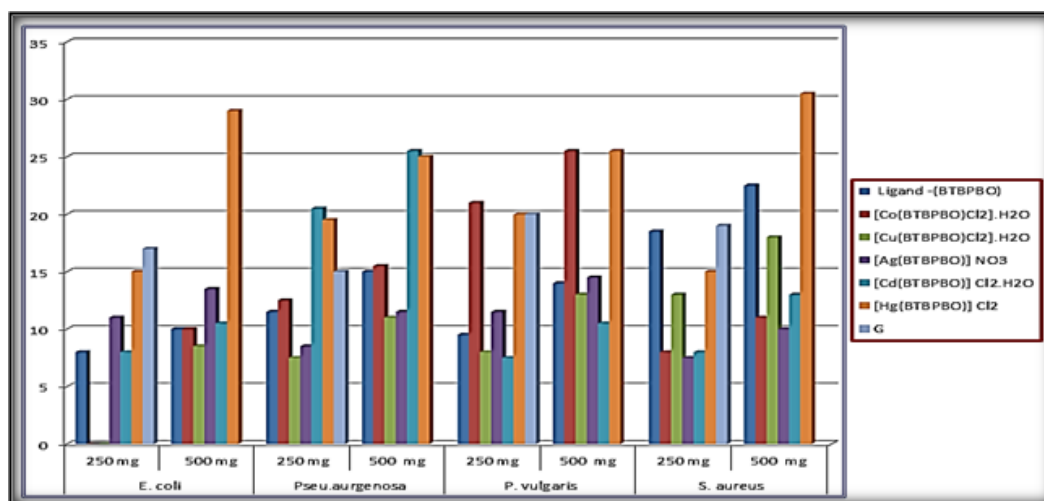


Figure 1: Statistical representations for biological activity of the synthesized ligand and its metal complexes

Molar conductance measurements

The molar conductivity of all the complexes was measured in the ethanol solvent at a concentration of 10^{-3} M and laboratory temperature. It was found that the conductivity measurements in the solvent correspond to the assumed formulas of the complexes. Copper and cobalt complexes showed conductivity values equal to 17.5 and 14.3 $\text{ohm}^{-1}\text{cm}^2\text{mole}^{-1}$, respectively, indicating that these complexes have non-ionic characteristics. On the other hand, the other complexes showed molar conductivity at the range (39.4-79.4 $\text{ohm}^{-1}\text{cm}^2\text{mole}^{-1}$) which indicated that the silver complex has a 1:1 ionic properties while the cadmium and mercury complexes have an ionic ratio of 1: 2 [35].

Biological Activity

Figure 1 and Table (5) presents the maximum activity shown by mercury complex against *S. aureus* and it was more active than antibiotic (Gentamycin). In addition, it exerted good antibacterial activities against all other test bacteria. However, Co(II) and Cu(II) complexes at a concentration of 250mg/ml were not effective against *E. coli*. All BTBPBO complexes have shown good antibacterial activity against all test bacteria at a concentration of 500 mg/ml.

CONCLUSION

In current study, the new ligand was prepared by reacting 2-mercaptobenzothiazole with 4,4-diaanilinmethane, then the product reacted with diacetyl monoxime. The ligand (BTBPBO) and its complexes with metals chlorides of [Co (II), Cu (II), Ag (I), Cd (II), and Hg (II)] were characterized by physical and spectral methods. The ligand coordinates with transitional metal ions through the nitrogen atoms of the azomethine group of imine, oxime and benzothiazole ring as well as the nitrogen atom of the secondary amine group which made the ligand behave as tetradentate ligand.

From above results, the structures of the complexes are tetrahedral geometry, except Co(II) and Cu(II) complexes are octahedral geometry. Also, all BTBPBO complexes have produced good antibacterial activity against all test bacteria .

Ethical Clearance: Permission for carrying out the study were obtained from the Department of chemistry, College of education/ University of Al- Qadisiyah, Iraq.

Financial Disclosure: There is no financial disclosure.

Conflict of Interest: None to declare.

REFERENCES

- Ibrahim MN and Sharif SE. "synthesis, characterization and use of Schiff Bases as fluorimetric analytical reagents" E-Journal of Chemistry. 2007; 4: 531-535.
- Shanthalakshmi K, Bhat M and Belagali S. "Synthesis of Benzothiazole Schiff's Bases and screening for the Anti-Oxidant Activity" J.Chemical and Pharmaceutical Research. 2016; (10): 240-243.
- Xavier A and Srividhya N. "Synthesis and study of Schiff base ligands." Journal of Applied Chemistry. 2014; 7(11): 06-15.
- Dhar DN and Taploo CL. "Schiff-bases and their applications" J.Sci Ind.Res. 1982; 41: 501-506.
- Venugopal KN, Jayashree BS. "Microwave-induced synthesis of Schiff bases of aminothiazolyl bromocoumarins as antibacterials" Indian Pharm Sci. 2008; 70: 88-91.
- Li Y, Yang ZS, Zhang H, Cao BJ and Wang FD. "Artemisinin derivatives bearing Mannich base group: synthesis and antimalarial activity" Bioorg Med Chem. 2003; 11: 4363-4368.
- Catalano A, Defrenza I, Muraglia M, Carrier A, Bambeke F, Rosato A, Corbo F and Franchini C. "2-Aminobenzothiazole derivatives: search for new antifungal agents" European Journal of Medicinal Chemistry. 2013; 64: 357-364.
- Doma A, Kulkarni R, Garlapati A and Radha P. "Synthesis and anti-inflammatory activity of novel pyrimidino benzothiazole amine derivatives" Pharmacophore. 2014; 5(2): 331-342.
- Soni B, RanawatM, Sharma R, Bhandari A and Sharma S. "Synthesis and evaluation of some new benzothiazole derivatives as potential antimicrobial agents" Eur J Med Chem. 2010; 45: 2938-2942. .
- Venkatesh P and Pandeya SN. "Synthesis, characterisation and anti-inflammatory activity of some 2-amino benzothiazole derivatives". International Journal of ChemTech Research. 2009; 1(4): 1354-1358.
- Ma ZH, Han HB, Zhou ZB and Nie J. "SBA-15-supported poly (4-styrenesulfonyl (perfluorobutylsulfonyl) imide) as heterogeneous Brønsted acid catalyst for synthesis of diindolylmethane derivatives" Journal of Molecular Catalysis. 2009; 1: 46-53.
- Ashraf MA, Mahmood K, Wajid A, Maah M and Yusoff I. "Synthesis, characterization and biological activity of Schiff bases" IPCBEE. 2011; 10: 1-7.
- Milios C, Stamatatos T, Kyritsis P, Terzis A, Raptopoulou C, Vicente R, Escuer A and S.Perlepes"Phenyl 2-Pyridyl Ketone and Its Oxime in Manganese Carboxylate Chemistry: Synthesis, Characterisation, X-ray Studies and Magnetic Properties of Mononuclear, Trinuclear and Octanuclear Complexes". European Journal of Inorganic Chemistry. 2004; 14: 2885-2901.
- AL-Adilee JK, Abass AK and Taher AM. "Synthesis of some transition metal complexes with new heterocyclic thiazolyl azo dye and their uses as sensitizers in photo reactions" J Molecular structure. 2016; 1108: 378-397.
- Aktan E and Uyar T. "Benzothiazol-3-ium cationic Schiff base surfactants: synthesis, surface activity and antimicrobial applications against pathogenic and sulfur reducing bacteria in oil fields" Journal of Chemistry. 2017; 1-10.

- 16- Kricheldorf h, Kreiser-Saunders I and Boettcher C. "Polylactones: 31. Sn (II) octoate-initiated polymerization of L-lactide: a mechanistic study". *Polymer*. 1995; 36(6): 1253-1259.
- 17- Al-Adilee K and Kyhoiesh H. "Preparation and identification of some metal complexes with new heterocyclic azo dye ligand 2-[2--(1-Hydroxy-4-Chloro phenyl) azo]-imidazole and their spectral and thermal studies" *Journal of Molecular Structure*. 2017; 1137: 160-178.
- 18- Kurtoglu N. "Synthesis, characterization, chelation with transition metal ions, and antibacterial and antifungal studies of the 4-[(E)-phenyldiazenyl]-2-[(E)-(phenylimino) methyl] phenol dye" *Journal of the Serbian Chemical Society*. 2009; 74(8-9): 917-926.
- 19- Mekhalif Z, Fonder G, Auguste D, Laffineur F and Delhalle J. "Impact of the anchoring groups X (-SH,-S-S,-SeH and-Se-Se-) of CF₃ (CF₂)₃ (CH₂)₁₁X molecules self-assembled on oxidised electroplated copper" *Journal of Electroanalytical Chemistry*. 2008; 618: 24-32.
- 20- Kok S, Gambari R, Chui C, Yuen M, Lin E, Wong R, Lau F, Cheng G, Lam W, Chan S and Lam K. "Synthesis and anti-cancer activity of benzothiazole containing phthalimide on human carcinoma cell lines" *Bioorganic & medicinal chemistry*. 2008; 16(7): 3626-3631.
- 21- Inamdar S, More V and Mandal S. "CuO nano-particles supported on silica, a new catalyst for facile synthesis of benzimidazoles, benzothiazoles and benzoxazoles". *Tetrahedron Letters*. 2013; 54(6): 579-583.
- 22- Gowri M and Thangadurai T. "Novel Heterocyclic Schiff Base,(Z)-4-((2-((2-Aminophenyl) disulfanyl) phenylimino)(Phenyl) Methyl)-3-Methyl-1-Phenyl-1H-Pyrazol-5-ol Crystals for Enzymatic Studies" *Molecular Crystals and Liquid Crystals*. 2015; 606(1): 199-207.
- 23- Misra P, Ravichandiran V and Aanandhi M. Design, Synthesis and In Silico Molecular Docking Study of N-carbamoyl-6-oxo-1-phenyl-1, 6-dihydropyridine-3-carboxamide derivatives as Fibroblast growth factor 1 inhibitor" *Research Journal of Pharmacy and Technology*. 10(8): 2527-2534.
- 24- Yadav K, Kumar A, Misra N and Brahmachari G. "Structure, spectroscopic analyses (FT-IR and NMR), vibrational study, chemical reactivity and molecular docking study on 3, 3'-((4-(trifluoromethyl) phenyl) methylene) bis (2-hydroxynaphthalene-1, 4-dione), a promising anticancerous bis-lawsone derivative". *Journal of Molecular Structure*. 2018; 1154: 596-605.
- 25- Awale AG, Gholse SB and Utale PS. "Synthesis, Characterization and Antimicrobial activity of 2-Amino-1, 3-benzothiazole, Schiff bases and Azo dyes of 2-Amino-1, 3-benzothiazole" *Journal of Pharmacy and Biological Sciences*. 2013; 6(2): 01-07.
- 26- Uruş S, Karabör M and Köksal H. "Synthesis, characterization and solid-phase extraction properties of novel bis (diazo-azomethine) ligands supported on mesoporous silica" *Applied Organometallic Chemistry*. 2018; 32(1): 4022-4031.
- 27- Byabartta P and Laguna M. "A novel series of nickel (II)-dppera-lylazoimidazole complexes. Synthesis and spectroscopic characterization" *Transition Metal Chemistry*. 2007; 32(2): 187-192.
- 28- Pokharia M, Yadav WJ, Mishra H, Pandey N, Tilak R and Pokharia S. "Synthesis, spectroscopic characterization, biological activity and theoretical studies of (E)-N3-(2-chlorobenzylidene)-H-1, 2, 4-triazole-3, 5-diamine" *Journal of Molecular Structure*. 2017; 1144: 324-337.
- 29- Brandan S. "Structural and vibrational properties of three species of anti-histaminic diphenhydramine by using DFT calculations and the SQM approach" *Chemistry Journal*. 2018; 1(1): 88-113.
- 30- Mary Y, Al-Shehri M, Jalaja K, Al-Omary F, El-Emam A, Panicker C, Armaković S, Temiz-Arpaci O and Van Alsenoy C. "Synthesis, vibrational spectroscopic investigations, molecular docking, antibacterial studies and molecular dynamics study of 5-[(4-nitrophenyl) acetamido]-2-(4-tert-butylphenyl) benzoxazole" *Journal of Molecular Structure*. 2017; 1133: 557-573.
- 31- Al-Zaidi BH, Abed A, Hafedh F and Niseaf A. "Synthesis, Characterization and Studying the Enzyme Activity of New Benzothiazole Schiff Base Ligand (HL) and Its Complexes with Some of Metal Ions". *Ibn AL-Haitham Journal For Pure and Applied Science*. 2017; 30(2): 125-140.
- 32- Gorelsky S and Lever A. "Electronic structure and spectra of ruthenium diimine complexes by density functional theory and INDO/S. Comparison of the two methods" *Journal of Organometallic Chemistry*. 2001; 635(1-2): 187-196.
- 33- Jamel HO, Adnan S, Mugheer TH and Jasim LS. "Synthesis and Characterization of the Ligand (S, S'-Bis (Benzo [d] Oxazol-2-yl) 2, 2'-((Methylenebis (4, 1 Phenylene)) Bis (Azanediyl)) Diethanethioate (BMPAE) and it's Complexes with Some Transition Metals Ions" *Journal of Global Technology*. 2017; 8(9): 76-85.
- 34- Wakil A, Okediran S, and Alao O. "Studies on Some Metal (II) Complexes of Mixed Ligands-Benzoic and N, N'-Dimethyldithiocarbamic Acids" *Chem J*. 2016; 6(1): 27-31.
- 35- Geary WJ. "The use of conductivity measurements in organic solvents for the characterisation of coordination compounds" *Coordination Chemistry Reviews*. 1971; 7: 81-122.