



Original Research Article

Spectroscopic and Antimicrobial Studies of Some Metal Complexes of Furfural Schiff Base Derivative Ligand

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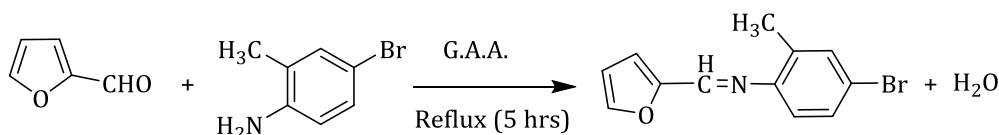
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ABSTRACT

A new furfural Schiff base derivative ligand (L-FSB) named N-(4-Bromo-2-methylphenyl)-1-(furan-2-yl)methanimine, was synthesized from the condensation reaction of furfural (fur) with 4-Bromo-2-methylaniline (bma) in 1:1 molar ratio. A new series of VO(II), Cr(III), Mn(II), Co(II), Ni(II), Cu(II), Zn(II), and Cd(II) metal complexes are synthesized according to the metal content analysis in an 2:1 ligand:metal ratio. The stereochemistry of the ligand complexes have been deduced by Fourier Transform-Infra Red (FT-IR), Atomic Adsorption (A.A), Ultra violet-Visible Spectra (UV-Vis Spectra), (Mass Spectra, Proton,¹³Carbon-Nuclear Magnetic Resonance) (¹H-NMR,¹³C-NMR) for ligand), magnetic susceptibility at 25°C and conductivity measurements. From the FT-IR data the coordination behavior of the ligand is a neutral monodentate ligand coordinate to the metal ions through azometane nitrogen. Electronic spectra analysis study revealed that the suggested geometrical structure of all complexes are distorted octahedral geometry except Zn(II) and Cd(II) complexes are tetrahedral and this study was confirmed by magnetic moment and conductance measurements. The antimicrobial activities of the synthesized Schiff base ligand and its complexes were screened against three pathogenic microbes: *Escherichia coli* (Gram-negative bacteria), *Staphylococcus aureus* (Gram-positive bacteria), and fungal strains (*Candida albicans*) were identified the most efficient biologically active compounds. The results of studies showed that potential is related to the structure and nature of ligand and their complexes.

GRAPHICAL ABSTRACT



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Introduction

The processes of designing drugs from organic compounds with new and practically important biological behaviors is required organic interactions involving the condensation of two or more types of molecules to obtain a new derived from imine compounds as a commonly used compounds for this purpose [1-4]. The reaction of condensation of the primary amines with aldehydes or ketones gives an important product. The Schiff base reaction was done under normal conditions. The presence of a Schiff base in our interactions is of great importance due to the stability of complexes of metal ions with different oxidation states and because of its involvement in many vital processes on a large scale such as industrial fields and as catalysts for reactions in addition to its significant wide involvement in biological activities [5]. The stable structure of metal complexes is attributed to the nitrogen lone pair electrons on azomethine (-N=CH) bonding [6]. Donor atoms of Schiff base ligand can be enhanced the antibacterial activity through the coordination to metal ions [7-9]. The interaction of metal ions with Schiff base ligands can give structures of different geometric shapes and have various applications such as their use in organometallic chemistry as anti-tumor, anti-cancer, anti-bacterial, anti-viral, and medicinal compounds designed, field of geology, as catalysts, anti-bacterial, anti-fungal agents, antiviral agents and for the design of important medicinal compounds [10, 11]. The effect of PH and concentrations on donor tetradentate ligands type N_2O_2 on the formation of transition metal complexes have been studied [12]. New Schiff base mixed ligand complexes of β -Enaminone with 8-hydroxyquinoline and Oxalic Acid with Schiff base trimethoprim chelates play an important role in biological processes such as the activation of transport substances across membranes, storage, and enzymes [13, 14]. Amines derived from furfurals or furfurylamines present diverse applications such as industry, pharmaceutical compounds, synthetic resins, polymers, agrochemicals, antiseptic agents, and pesticides as well as Barmastine and an anti-

hepatitis-B [15, 16]. In this paper, we have been synthesized, characterized, and conducted antimicrobial studies of new Schiff base ligand N-(4-Bromo-2-methylphenyl)-1-(furan-2-yl)methanimine (L-FSB) and its metal complexes with: VO(II), Cr(III), Mn(II), Co(II), Ni(II), Cu(II), Zn(II), and Cd(II).

Materials and Methods

All used chemicals reagents were of the analytical propose and the highest purity from (BDH). All the organic solvents are absolute, Dimethylsulphoxide (DMSO) ethanol and diethylether were either spectroscopic pure from (Aldrich).

Instruments

The melting point was registered on "G. Kamp, device model SMP30 at College of Education of Pure Science, Ibn Al-Hathiam. FT-IR are performed in the range of 4000-400 cm^{-1} in KBr discs and in the range of 4000-200 cm^{-1} in CsI discs on (FT-IR) Shimadzu type-8400S. Spectra were recorded at Laboratories of the College of pure Sciences, University of Diyala. 1H -NMR and ^{13}C -NMR of the new ligand was recorded by using (Brucker-500 MHz spectrophotometer) was measured in DMSO- d_6 . The chemical shifts are in ppm relative to TMS were performed at University of Tehran, Iran. GC-M spectrum was performed using Agilent mass spectrophotometer, 5973N.S.D Mass, at the laboratory of University of Tehran, Iran. Magnetic susceptibility values were obtained at 25 °C using Auto Magnetic susceptibility Balance Sherwood Scientific using the Faradays method at Al-Mustansiriya University. TLC for the ligand (L-FSB) was performed in aluminum plates coated by (0.3 mm) layer of silica gel Fluka type (F254) and detected in Iodine. Conductivity measurements were registered using conductivity meter type VIRA, B3000 in DMSO solvent at laboratory of (BPC), Baghdad. UV-Vis spectroscopy were measured by using (SHIMADZU-UV-240) at the wavelength range (200-1100 nm), using match quartz cells (1 cm) and DMSO as a solvent at laboratory of (BPC), Baghdad. The metal content of complexes were measured using Shimadzu Emission

spectrophotometer type AA (680) at Ibn Sina Company, Ministry of Industry Baghdad, Iraq.

Biological activities

Method of preparation of agricultural media

The nutrient media (Muller Hinton agar) prepared from (mast group) was prepared by gram of powder in a liter of distilled water, and (pH = 7.3), and then sterilized by Auto Cleave. This medium was used for the purpose of growing microorganisms and studying the antagonistic activity of chemicals against the isolates used of this study.

Preparation of microorganism suspension

The suspension of microorganisms was prepared by taking colonies from each of the microorganisms under study, and placing it in sterile physiological saline at a concentration of 0.85%. The Petridis dishes were used in its preparation to examine the biological activity against the chemical compounds under study.

Microorganisms testing the inhibitory activity of complexes in facultative

The agar well diffusion method was used to observe the effect of ligands and chemical complexes under study on the growth of microorganisms by pouring 20-25 millimeter of agar medium into each plate and keeping the plate after it was cooled in the incubator for a whole day (1 hour) at 37 °C to ensure that there is no contamination of the dishes. The plate was soaked with 10 mL of the prepared microorganism suspension as mentioned in the previous paragraph containing 1.5×10^8 cells/mm, and then spread evenly on the surface of agar medium using a glass spreader, a hole was made on the surface of the culture medium with a glass spreader. Chemical complexes by 100 micro ml for each well at a concentration of 1×10^{-3} M, with the remainder of control hole containing the solvent (DMSO), the dishes were left for half an hour in the refrigerator at 4 °C, and after that they were incubated in the incubator at 37 °C.

Synthesis of ligand N-(4-Bromo-2-methylphenyl)-1-(furan-2-yl)methanimine (L-FSB)

2.58 g, (26.8 mmol) of furfural was taken in a conical flask with a capacity of 100 mL, and then 15 mL of absolute ethanol was added to it, the mixture was left to stirring for 10 minutes. After that three drops of glacial acetic acid were added to the mixture, and the stirring continued for 10 minutes (5 g, 26.8 mmol) of (2-amino-5-bromotoluene) dissolved in absolute ethanol (25 ml) was added to it. The mixture was refluxing and stirring at 70-80 °C for 5 hours, while the reaction was monitored through TLC technique ($R_f = 0.84$), the solution was cooled, and then the precipitate was filtered and left to dry giving a pale yellow precipitate, and recrystallized using hot ethanol.

Synthesis of (L-FSB) metal complexes

Synthesis of $[Cr (L-FSB)_2 (H_2O)_2 Cl_2] Cl \cdot 8H_2O$ complex

(0.15 g, 0.56 mmol) of chromium trichloride hexahydrate ($CrCl_3 \cdot 6H_2O$) was dissolved in 5 mL of absolute ethanol, and then added gradually to the mixture (0.2 g, 1.21 mmol) of ((L-FSB) ligand dissolved in 20 mL of absolute ethanol). The mixture was left for continuous stirring for half an hour, and then the mixture was refluxing at a temperature 70-80 °C for 3 hours. Thereafter, the solution was left to dry at room temperature forming a violet precipitate, and then the precipitate was collected and recrystallized with hot ethanol, to obtain dark violate precipitate.

Synthesis of $[(M)_n(L-FSB)_n (Y)_n (X)_n] nZ \cdot nb$ complexes

[(L-FSB) = Furfural Schiff Base Derivative Ligand]
 [Y = H_2O , X = Cl] Z = (SO_4) for VO(II) complex only
 or Cl, b = H_2O ,

n = (1, 2, 3, 4, ...)

M_n (II) = (VO)₂, Mn, Co, Ni, Cu, Zn and Cd

(L-FSB)_n = 4, 2, 2, 2, 2 and 2

(Y)_n = 4, 2, 3, 3, 3, 1 and 0

(X)_n = 0, 2, 1, 1, 1, 1 and 2

(Z)_n = 2, 0, 1, 1, 1, 1 and 0

(b)_n = 18, 7, 2, 5, 3, 4 and 11

The same previous method was followed in paragraph (2-5-1) to synthesize the following metal complexes using of (1 mmol) of metal ion salts: (0.180 g, $\text{VO}_4\cdot\text{H}_2\text{O}$), (0.197.93 g, $\text{MnCl}_2\cdot 4\text{H}_2\text{O}$), (0.237 g, $\text{CoCl}_2\cdot 6\text{H}_2\text{O}$), (0.237 g, $\text{NiCl}_2\cdot 6\text{H}_2\text{O}$), (0.170 g, $\text{CuCl}_2\cdot 2\text{H}_2\text{O}$), (0.136 g, ZnCl_2) and (0.201 g, $\text{CdCl}_2\cdot \text{H}_2\text{O}$) with (2 mmol) of the ligand (0.528 g, (L-FSB)) to give different colors of complexes precipitates which were collected by filtration, washed with ethanol, and then vacuum dried.

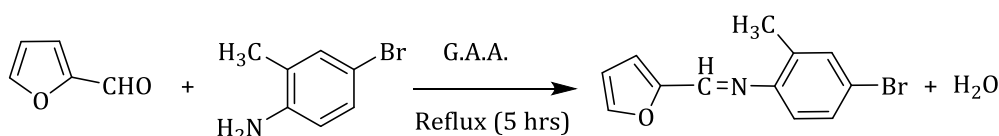
Results and Discussion

Synthesis and physical properties of (L-FSB) ligand and It's metal complexes

The new Schiff base (L-FSB) was prepared as a furfural Schiff base derivative by the condensation reaction of furfural with of 2-amino-5-

bromotoluene in a mole ratio (1:1), respectively. The reaction is illustrated in Scheme 1.

The formation of (L-FSB) ligand was characterized and confirmed by melting point, TLC, FT-IR, UV-Vis, $^1\text{H-NMR}$, $^{13}\text{C-NMR}$, and mass spectra data. It was found to be stable towards air. This ligand was sparingly soluble in methanol ethanol, acetone, chloroform, ethyl acetate, benzene, and soluble in DMSO, DMF, and THF diethyl ether, but insoluble in water. The coordinating behavior of synthesized (L-FSB) ligand with their metal ions (VO(II), Cr(III), Mn(II), Co(II), Ni(II), Cu(II), Zn(II), and Cd(II)) have been studied. Analytical data of metal content for the ligand (L-FSB) and its metal complexes suggest that (metal: ligand) was (1:2) stoichiometry. Most of complexes have high melting points and show stability. The physical properties of ligand (L-FSB) and their complexes are presented in Table 1.



Scheme 1: Condensation reaction between furfural and 2-amino-5-bromotoluene

Table 1: Physical properties of ligand (L-FSB) and its complexes

Ligand and Complexes Molecular Formula	Color	mp (°C) Dc (°C)	Molecular Weight g/ mole	Yield (%)	M% found (Calculated)
(L-FSB) $\text{C}_{12}\text{H}_{12}\text{NO}_2\text{Br}$	Pale Yellow	105-107	164	47.00	-
$[(\text{VO})_2(\text{L-FSB})_4(\text{H}_2\text{O})_4](\text{SO}_4)_2\cdot 18\text{H}_2\text{O}$ $\text{C}_{48}\text{H}_{84}\text{Br}_4\text{N}_4\text{O}_{36}\text{S}_2\text{V}_2$	Dark Green	(183-185)	1778.82	62.00	9.939 (7.53)
$[\text{Cr}(\text{L-FSB})_2(\text{H}_2\text{O})_2\text{Cl}_2]\text{Cl}\cdot 8\text{H}_2\text{O}$ $\text{C}_{24}\text{H}_{40}\text{Br}_2\text{Cl}_3\text{CrN}_2\text{O}_{12}$	Violate	176-178	866.75	51.01	8.95 (6.00)
$[\text{Mn}(\text{L-FSB})_2(\text{H}_2\text{O})_2\text{Cl}_2]\cdot 7\text{H}_2\text{O}$ $\text{C}_{24}\text{H}_{38}\text{Br}_2\text{Cl}_2\text{MnN}_2\text{O}_{11}$	Pale Brown	(205-207)	816.22	63.04	6.74 (6.73)
$[\text{Co}(\text{L-FSB})_2(\text{H}_2\text{O})_3\text{Cl}]\text{Cl}\cdot 2\text{H}_2\text{O}$ $\text{C}_{24}\text{H}_{30}\text{Br}_2\text{Cl}_2\text{CoN}_2\text{O}_7$	Dark Violate	195-197	748.16	80.95	8.60 (7.88)
$[\text{Ni}(\text{L-FSB})_2(\text{H}_2\text{O})_3\text{Cl}]\text{Cl}\cdot 5\text{H}_2\text{O}$ $\text{C}_{24}\text{H}_{36}\text{Br}_2\text{Cl}_2\text{N}_2\text{NiO}_{10}$	Reddish brown	116-118	801.98	75.77	7.47 (7.32)
$[\text{Cu}(\text{L-FSB})_2(\text{H}_2\text{O})_3\text{Cl}]\text{Cl}\cdot 3\text{H}_2\text{O}$ $\text{C}_{24}\text{H}_{32}\text{Br}_2\text{Cl}_2\text{CuN}_2\text{O}_8$	Dark Brown	120-122	770.79	72.09	7.49 (8.24)
$[\text{Zn}(\text{L-FSB})_2(\text{H}_2\text{O})\text{Cl}]\text{Cl}\cdot 4\text{H}_2\text{O}$ $\text{C}_{24}\text{H}_{30}\text{Br}_2\text{Cl}_2\text{N}_2\text{O}_7\text{Zn}$	Dark Brown	140-142	754.61	57.14	7.90 (8.66)
$[\text{Cd}(\text{L-FSB})_2\text{Cl}_2]\cdot 11\text{H}_2\text{O}$ $\text{C}_{24}\text{H}_{42}\text{Br}_2\text{CdCl}_2\text{N}_2\text{O}_{13}$	Pale Brown	158-160	909.72	50.94	11.30 (12.35)

Spectroscopy studies

FT-IR spectra of the ligand (L-FSB)

The FT-IR spectrum of the new ligand (L-FSB) appeared of a sharp, split, and a new band at 1630 and 1624 cm^{-1} , which is due to the formation of azomethine. ν (CH=N) is an indication of the condensation of amino group NH_2 of 4-Bromo-2-methyl aniline compound with the aldehyde group of the furfural and its converted to azomethine group [17].

FT-IR spectra of ligand (L-FSB) and its metal complexes

The infrared spectrum of the free Ligand (L-FSB), Figure 1 appearing band at 1631 and 1624 cm^{-1} attributed to azomethine was shifted to lower frequency by 4-11 cm^{-1} in all complexes except copper complex was shifted to higher frequency about 62 cm^{-1} with change in the intensity of band of cadmium complex indicating to the participation of nitrogen atom of azomethine in the coordination of complexes [18]. The ligand (L-FSB) showed broad band at 3200 cm^{-1} due to

presence of water molecular. In metal complexes showed broad and strong absorption bands in the range of 3680-3221 cm^{-1} due to the OH stretching vibration of lattice water [19] while the presence of coordinated $\nu(\text{M-O})$ was detected by the appearance of bands at the range of 594-509 cm^{-1} in all complexes [20] except for Cd(II) complex. Another evidence of presence of the coordinated bands of aqua water $\nu(\text{M-OH}_2)$ were appeared of new bands at in the range 867-987 cm^{-1} in all complexes except Cd(II) complex. Another new bands was appeared in VO(II) complex, Figure 2 at 979 cm^{-1} and 1041 cm^{-1} which is due to stretching vibration of $\nu(\text{V=O})$ and $\nu(\text{SO}_4)^{2-}$ free ion [21]. On the other hand all complexes showed new bands at the range of 432-478 cm^{-1} , due to $\nu(\text{M-N})$ and another new band at the rang of 275-378 cm^{-1} except for VO(II) complex, is due to the stretching vibration of $\nu(\text{M-Cl})$, and that confirmed the coordinated behavior of (L-FSB) was mono dentate through the coordinate by nitrogen atom of azomethine group [22]. All prominent absorption bands of the ligand (L-FSB) and its metal complexes are presented in Table 2.

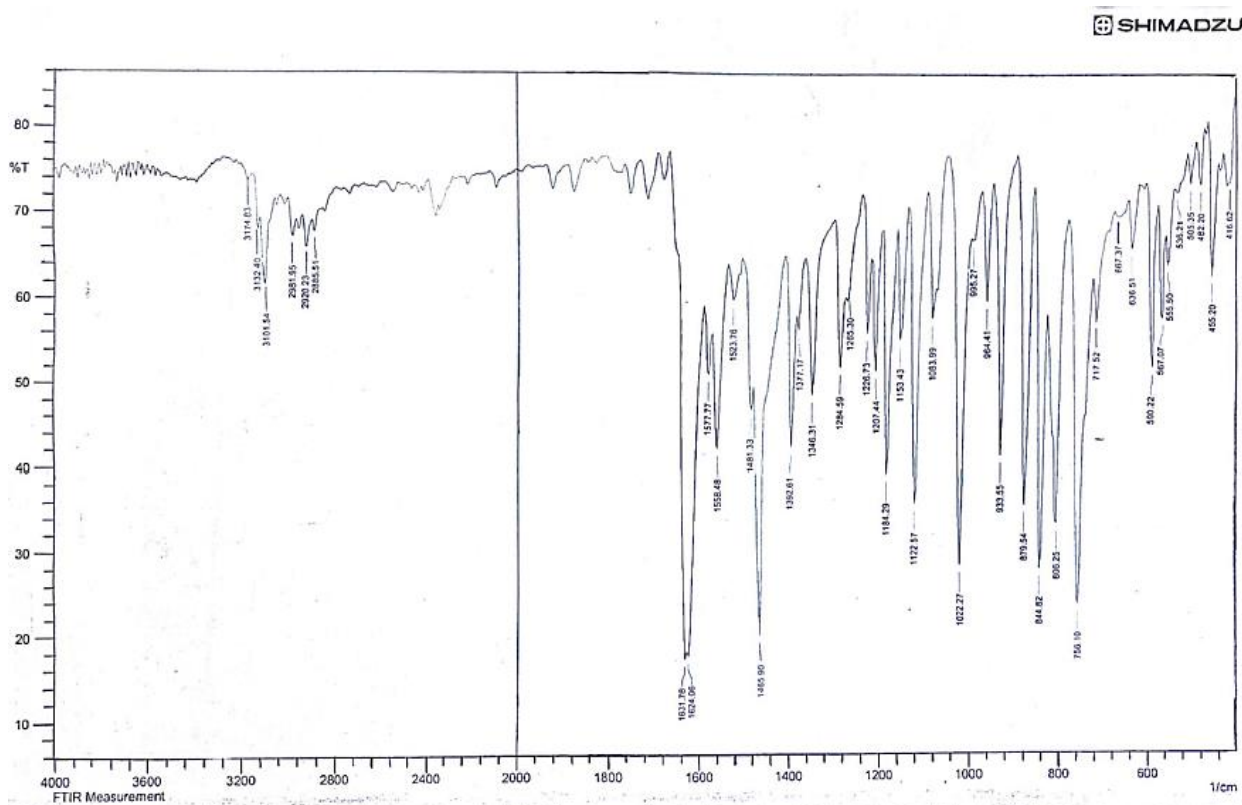


Figure 1: FT-IR spectrum of the ligand (L-FSB)

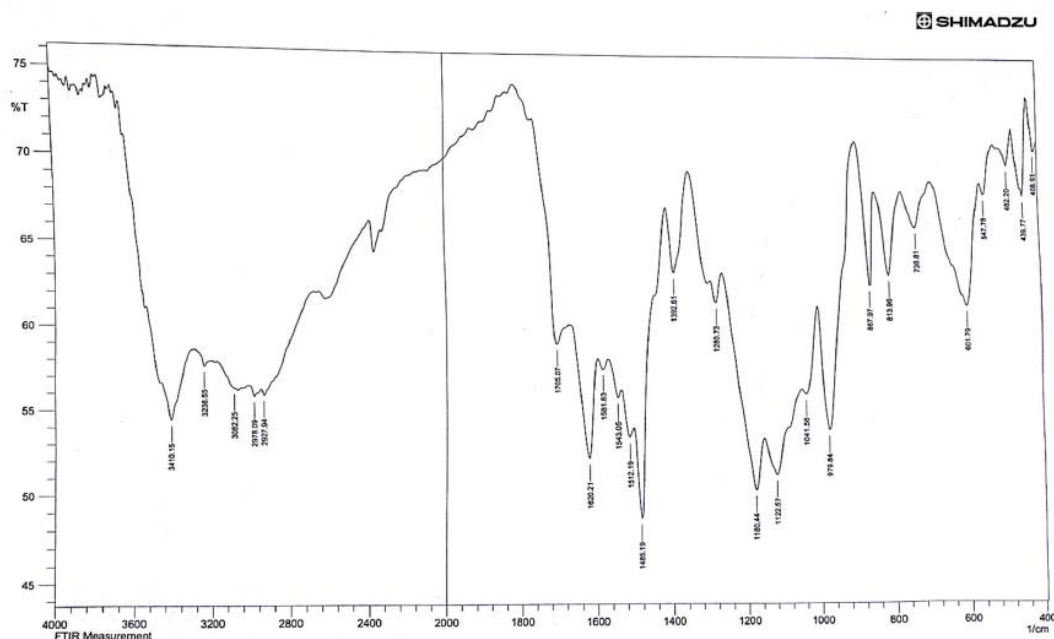


Figure 2: FT-IR spectrum of $[(VO)_2(L-FBS)_4(H_2O)_4](SO_4)_2 \cdot 18H_2O$ complex

Table 2: FT-IR spectra data of (L-FSB) and metal complexes

Ligand and complexes	$\nu(OH)$ Lattice	$\nu(C=N)$	$\nu(V=O)$ $\nu(SO_4)$	$\nu(OH_2)$ aquo	$\nu(M-O)$	$\nu(M-N)$	$\nu(M-Cl)$
(L-FSB) $C_{12}H_{12}NO_2Br$	3228(br)	1631,1624 (sh)	- -	-	-	-	-
$VO_2(L-FSB)_4(H_2O)_4$ $[(SO_4)_2 \cdot 18H_2O]$	3500- 3250(br)	1620(sh)	979(s) 1041(w)	867(s)	547(w)	439(m)	-
$[Cr(L-FSB)_2(H_2O)_2Cl_2]Cl \cdot 8H_2O$	3406- 3221(br)	1616(sh)	- -	867(vs)	540(s)	435(s)	275(s)
$[Mn(L-FSB)_2(H_2O)_2Cl_2] \cdot 7H_2O$	3680- 3248(br)	1620(m)	- -	867(vs)	509(w)	478(m)	375(s)
$[Co(L-FSB)_2(H_2O)_3Cl]Cl \cdot 2H_2O$	3417 (br)-(m)	1616(m)	- -	867(s)	594(s)	447(s)	308(s)
$[Ni(L-FSB)_2(H_2O)_3Cl]Cl \cdot 5H_2O$	3375- 3217(br)	1620(s)	- -	867(vs)	540(s)	435(vs)	300(vs)
$[Cu(L-FSB)_2(H_2O)_3Cl]Cl \cdot 3H_2O$	3228(br)	1693(m)	- -	887(s)	551(w)	455(w)	325(s)
$[Zn(L-FSB)_2(H_2O)Cl]Cl \cdot 4H_2O$	3441(br)	1627(sh)	- -	987(m)	567(m)	455(m)	378(s)
$[Cd(L-FSB)_2Cl_2] \cdot 11H_2O$	3476(s) 3305(s) 3240(s)	1631(sh)	- -	-	-	432(s)	347(s)

br = broad, m = medium, s = strong, vs = very strong, w = weak, vw = very weak, and sh = sharp

1H -NMR of the ligand (L-FSB)

The 1H -NMR spectra of the ligand (L-FSB), [Figure 3](#) appeared one signal at $\delta = 2.31$ ppm due to 3, protons of methyl group [23], and multiplet signals at the range of $\delta = 6.99$ -7.39 ppm due to 3 protons of aromatic ring, another signals at the

range of $\delta = 6.65$ -7.40, which due to the 3 protons of furan ring. The singlet signal at $\delta = 8.31$ ppm due to the H proton of the azomethine group and finally the chemical shift at $\delta = 2.52$ ppm is due to the DMSO solvent [24].

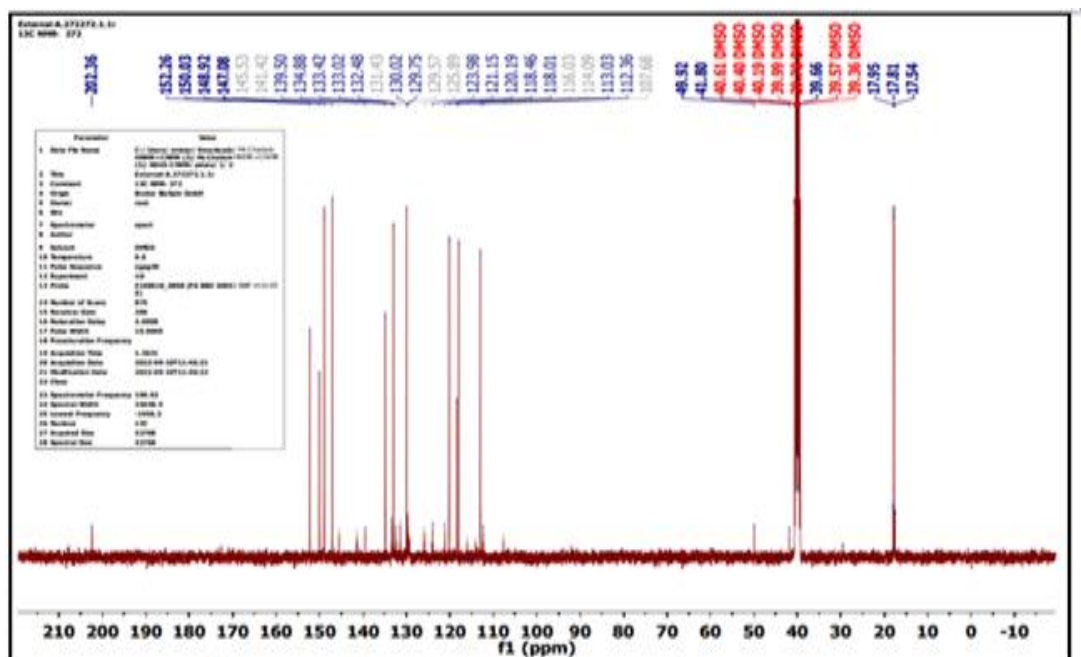


Figure 4: ¹³C-NMR spectrum of the ligand (L-FSB)

Table 3: Mass spectra fragments and abundance of the ligand (L-FSB)

Fragments	Peak (m/z)	Abundance (%)
[C ₁₂ H ₁₀ NOBr]	264	100
[C ₁₁ H ₈ NOBr]	250	1.08
[C ₁₀ H ₁₀ NBr]	235	64.32
[C ₁₂ H ₁₁ NO] ⁺	184	17.83
[C ₁₂ H ₁₀ NO]	183.2	60.00
[C ₇ H ₈ Br] ⁺	171	4.86
[C ₁₁ H ₉ NO] ⁺	170	1.08
[C ₁₀ H ₉ N]	141	3.78
[C ₇ H ₇] ⁺	91	8.10
[C ₆ H ₅] ⁺	77	21.08
[C ₅ H ₃] ⁺	63.2	21.35
[C ₄ H ₃] ⁺	51.2	23.24

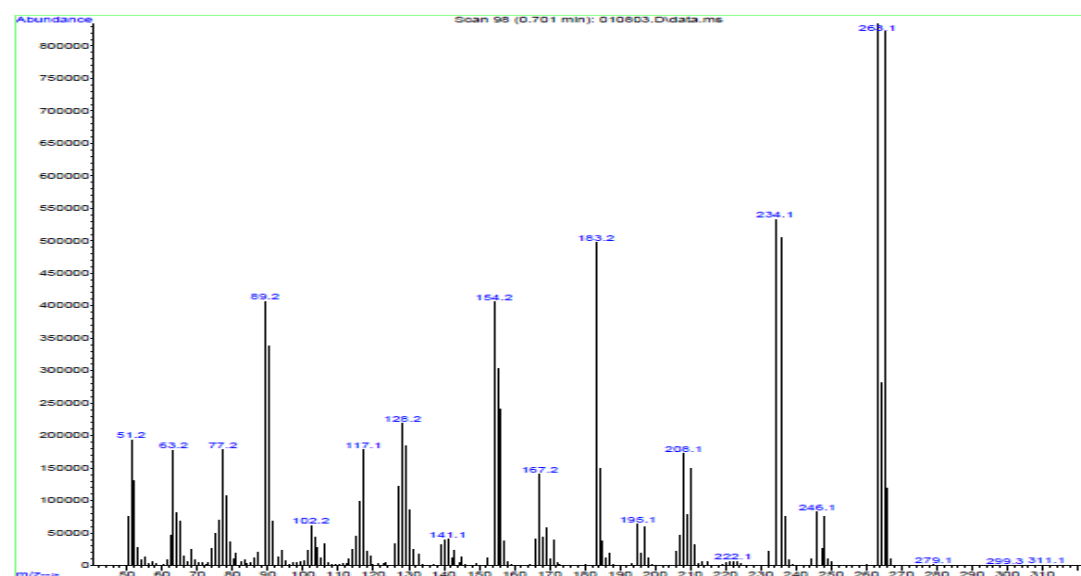


Figure 5: Mass spectrum of the ligand (L-FSB)

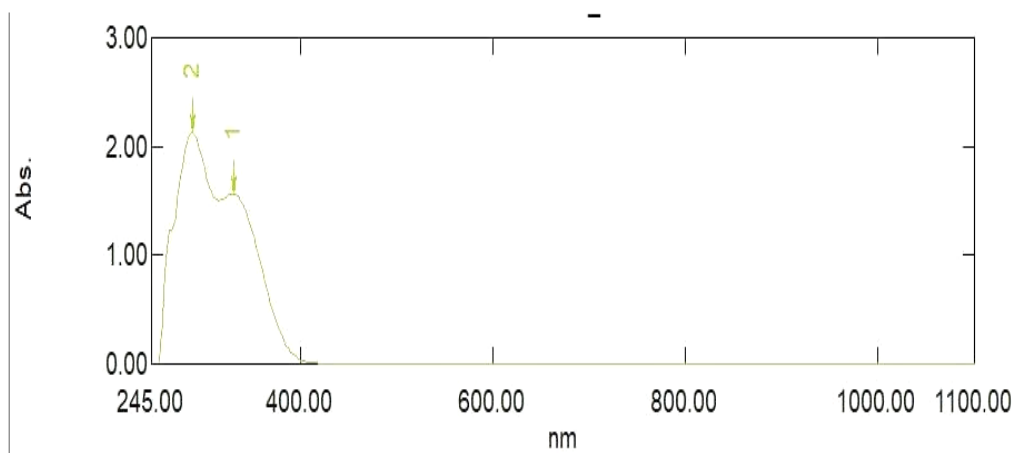


Figure 6: UV- Vis spectrum of the ligand (L-FSB)

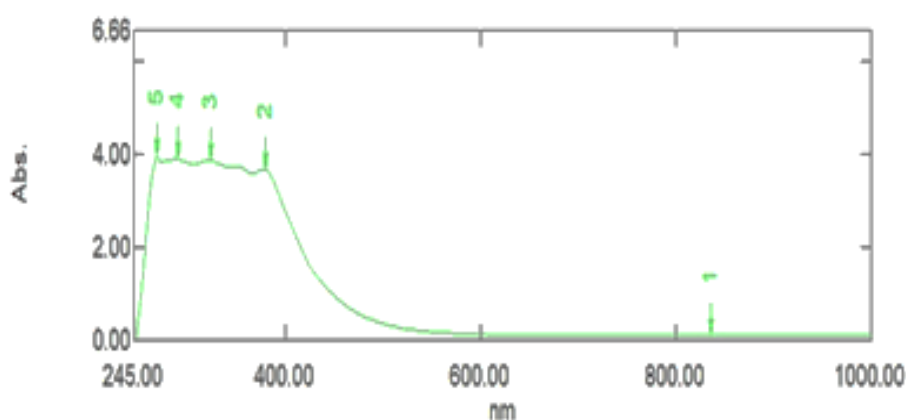


Figure 7: UV-Vis spectrum of $[(VO)_2(L-FBS)_4(H_2O)_4](SO_4)_2 \cdot 18H_2O$

UV-Vis spectrum of violate chromium(III) complex shows a band with broad intensity at 502 nm and 19220 cm^{-1} is attributed to (d-d) electronic transition type ${}^4A_{2g} \rightarrow {}^4T_{1g}(P) \nu_3$ and the other (d-d) transition bands did not appear or is very weak, based on these results of magnetic moments of Cr(III) was (3.85 B.M.) at room temperature and the molar conductivity value in DMSO was 1:1 electrolyte in addition of these results, FT-IR, and metal content, we suggested the distorted octahedral geometry of Cr(III) complex [30].

UV-Vis spectrum of pale brown manganese(II) complex appeared an absorption band at 352 nm and 28409 cm^{-1} is attributed to the charge transfer band. The measurement of magnetic susceptibility of manganese(II) solid complex showed a value at 5.49 BM at room temperature, which is due to the presence of five individual electrons with high spin state, and this supports by the measurements

value of molar conductivity in DMSO solvent was non-electrolyte in addition of these results, FT-IR, and metal content, we suggested the distorted octahedral geometry of Mn(II) complex [31].

UV-Vis spectrum of dark violate Cobalt(II) complex exhibiting two absorption bands at 602 nm and 16111 cm^{-1} and 672 nm and 14881 cm^{-1} , these bands are observed in the visible region center at 645 nm and 15496 cm^{-1} , this may be attributed to the transition ${}^4T_{1g}(F) \rightarrow {}^4T_{1g}(F) \nu_2$, the other, electronic transition bands type ${}^4T_{1g}(F) \rightarrow {}^4T_{2g}(F) \nu_1$ and ${}^4T_{1g} \rightarrow {}^4T_{1g}(P) \nu_3$ could not be detected or is very weak, so besides studying magnetic moments at room temperature of Co(II) complex was (2.3 B.M.) confirmed high spin of d^7 ion and that indicates the paramagnetic nature. The measurement value of molar conductivity in DMSO was 1:1 electrolyte. According to these results in addition to the results of FT-IR and metal

content, we suggested the distorted octahedral geometry of Co(II) complex [32].

UV-Vis spectrum of reddish brown Nickel(II) complex show electronic transition band with high intensity at 404 nm and 24752 cm^{-1} is attributed to (d-d) electronic transition type ${}^3A_{2g} \rightarrow {}^3T_{1g}(P)$ and the other two electronic transition bands type ${}^3A_{2g} \rightarrow {}^3T_{1g}(F)$ and ${}^3A_{1g} \rightarrow {}^3T_{2g}(F)$ could not detected or is very weak. The measurement of magnetic moment of nickel(II) solid complex showed a value at 2.86 B.M at room temperature, which is due to the presence of two individual electrons with high spin state, and this supports by the measurements value of molar conductivity in DMSO solvent was (1:1) electrolyte in addition of these results, FT-IR, and metal content, we suggested the distorted octahedral geometry of Ni(II) complex [33].

UV-Vis spectrum of dark brown Copper(II) complex exhibiting weak intensity adsorption band at 882 nm, 11338 cm^{-1} can be assigned to the electronic transition type (${}^2B_{1g} \rightarrow {}^2B_{2g}$). On the basis of these results, the measurements of magnetic moment value of the solid Cu(II) is 2.34 B.M. at room temperature and also confirming with the results of molar conductivity in DMSO solvent is (1:1) electrolyte, in addition to the results of FT-IR of metal content, we suggested the distorted octahedral geometry of Cu(II) complex [34, 35].

UV-Vis spectrum of dark brown Zinc(II) complex and pale brown Cadmium(II) complex. The existence of tail that which extends to the range of 420 nm, is due to the charge transfer spectrum of Zn(II) and Cd(II) complexes. The Zn(II) and Cd(II) complexes are diamagnetic, and the molar conductivity of Zn(II) complex is (1:1) electrolyte and for Cd(II) complex is non-electrolyte, so according to these transitions and in addition to the results of FT-IR and metal content, we suggested the tetrahedral geometry of Zn(II) and Cd(II) complex [36]. The UV-Vis Spectra data, magnetic moment, and molar conductance results of (L-FSB) complexes are listed in Table 4.

Antimicrobial activity studies

The antimicrobial studies of the newly synthesized furfural Schiff base ligand (L-FSB) and their metal complexes have tested against three pathogenic microbes as Gram-positive (*Staphylococcus aureus*), (*Escherichia coli*), and fungal strains (*Candida albicans*) using the disk diffusion method. The test (L-FSB) ligand and metal complexes were dissolved in (DMSO) to get a solution of 10 mg/mL [37, 38]. The biological activity studies of (L-FSB) and complexes are presented in Tables 5 and Figure 8.

Biological activity of prepared ligand (L-FSB) and its complexes against bacterial and fungal. The prepared ligand (L-FSB) showed inhibitory activity with the same amount against positive and negative bacteria. All its derived complexes showed the activity against Gram-negative and Gram-positive bacteria in various proportions. Cadmium(II) and Cobalt(II) complex is more effective than other complexes against bacteria (*Staphylococcus aureus*), while the complex of Cadmium(II) and Nickel(II) showed higher inhibitory activity than the rest of the complexes against the bacteria *E.coli*.

With regard to fungus, the prepared ligand (L-FSB) showed high inhibitory activity against *Candida albicans* compared with its activity against bacteria and also all the complexes derived from it showed effectiveness and in varying proportions, copper(II) and cadmium(II) complex showed a higher inhibitory activity than the rest of the complexes prepared against fungus. The reason for the effectiveness of the prepared ligand and its complexes against staph bacteria and *E.coli* bacteria are due to several reasons, including:

- 1- The solutions of these ligands and their complexes have the ability to dissolve the fatty layer of wall of these bacteria, which causes the liquids in the cell to leak out and destroy them.
- 2- The chelating nature of the prepared ligand (L-FSB), as it can form complexes with the metallic elements present in the cell body such as magnesium, zinc, calcium, copper, cobalt, and iron that microorganism's need, which strips these bacteria of these essential elements and disables them from her death [39, 40].

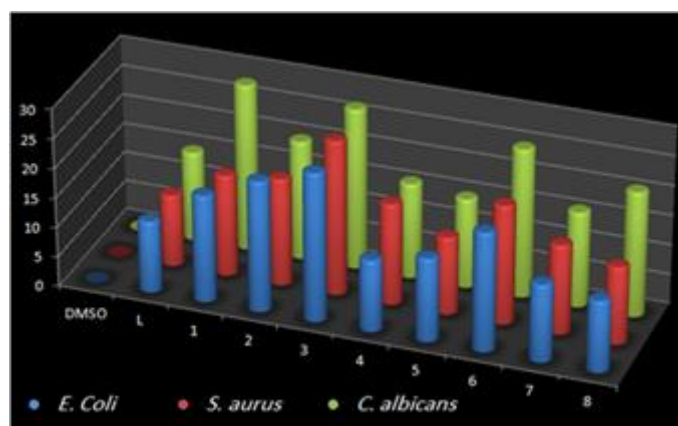
Table 4: UV-Vis spectra data , magnetic moment, and molar conductance results of (L-FSB) complexes

Ligand (L-FSB) and complexes	Band position λ (nm)	Band position ν (cm^{-1})	Molar extinction coefficient ϵ_{max} ($\text{dm}^3 \cdot \text{mol}^{-1} \cdot \text{cm}^{-1}$)	Assignments	Magnetic moment (B.M.)	Conductivity Λ_m ohm. $\text{cm}^2 \cdot \text{mol}^{-1}$	Suggested structure
(L-FSB)	288	34222	1295	$\pi \rightarrow \pi^*$ $n \rightarrow \pi^*$	-	2.07	
	330	30303	952				
[[VO] ₂ (L-FSB) ₄ (H ₂ O) ₄](SO ₄) ₂ .18H ₂ O	268	37313	224	C.T	-	31.8	Square pyramidal
	290	34483	219	L.F			
	324	30864	218	L.F			
	380	26316	207	$^1B_2 \rightarrow ^1A_1$			
	836	11962	7	$^1B_2 \rightarrow ^1E$			
Cr(L-FSB) ₂ (H ₂ O) ₂ Cl ₂ [Cl.8H ₂ O]	268	37313	456	$^4A_2g \rightarrow ^4T_1g(P) \nu_3$	3.85	64.0	Distorted Octahedral
	296	33783	451	L.F			
	502	19920	241	L.F			
[Mn (L-FSB) ₂ (H ₂ O) ₂ Cl ₂].7H ₂ O	266	37594	515	C.T	5.49	7.26	Distorted Octahedral
	282	35461	487	L.F			
	312	32051	486	L.F			
	352	28409	489	C.T			
[Co(L-FSB) ₂ (H ₂ O) ₃ Cl]Cl.2H ₂ O	268	37313	517	L.F	2.31	60.2	Distorted Octahedral
	300	33333	506	L.F			
	332	30120	510	L.F			
	602	16111	34	-			
	645	Mean center at 15496	32	$^4T_1g(F) \rightarrow ^4T_1g(F) \nu_2$			
	672	14881	32	-			
[Ni(L-FSB) ₂ (H ₂ O) ₃ Cl]Cl.5H ₂ O	268	526		L.F	2.86	94.5	Distorted Octahedral
	290	490		L.F			
	322	488		L.F			
	354	487		C.T			
	404	501		$^3A_2g \rightarrow ^3T_1g(P) \nu_3$			
[Cu(L-FSB) ₂ (H ₂ O) ₃ Cl] Cl.3H ₂ O	271	36900	207	L.F	2.34	38.4	Distorted Octahedral
	882	11338	26	$2B_{1g} \rightarrow 2B_{2g}$			

[Zn (L-FSB) ₂ (H ₂ O) Cl]Cl.4H ₂ O	268	37313	163	C.T	-	63.5	Tetrahedral
	288	34222	172	L.F			
[Cd(L-FSB) ₂ Cl ₂].11H ₂ O	268	37313	255	C.T	-	15.83	Tetrahedral
	288	34222	305	L.F			

Table 5: Inhibition zone in diameter (mm) of (L-FSB) and its complexes

Solvent, ligand and complexes	Bacteria		Fungal
	Escherichia coli	Staphylococcus aureus	
DMSO	-	-	-
(L-FSB)	12	12	15
Cu-(L-FSB) ₂	18	17	28
Ni-(L-FSB) ₂	22	18	20
Cd-(L-FSB) ₂	25	26	27
Mn-(L-FSB) ₂	12	17	16
Zn-(L-FSB) ₂	14	13	15
Co-(L-FSB) ₂	20	20	25
(VO) ₂ -(L-FSB) ₄	13	15	16
Cr-(L-FSB) ₂	12	13	21

**Figure 8:** The ratio of growth *E.Coli*, *S.aureus*, and *C.albicans* against (L-FSB) as well as their complexes at concentration (10^{-3} M)

Conclusion

A new series of metal complexes of VO(II), Cr(III), Mn(II), Co(II), Ni(II), Cu(II), Zn(II), and Cd(II) have been coordinated with new Schiff base derived from (bma) and (fur), in an (1 to 2) ratio (metal to ligand) based on the results of metal content (A.A). All of these compounds characterized using different techniques: FT-IR, UV-Vis spectra, (¹H-NMR, ¹³C-NMR, and mass spectra for ligand), magnetic moment and molar conductivity. FT-IR explains the metal coordinated through nitrogen atom of azomethine and oxygen atom of water. The FT-IR results of the ligand (L-FSB) were in good agreement with those obtained from ¹H-

NMR, ¹³C-NMR, and mass spectra. Conductance measurements values showed that VO(II), Cr(III), Co(II), Ni(II), Cu(II), and Zn(II) complexes are 1:1 electrolyte except Mn(II) and Cd(II) are non-electrolyte. The study of UV-Vis spectra and magnetic moment measurements support and confirmed the geometrical structure for all complexes are distorted octahedral except Zn(II) and Cd(II) complexes are tetrahedral. The biological analysis of (L-FSB) and its complexes against *Staphylococcus aureus* (G+), *E.Coli* (G-) bacteria, and *Candida albicans* was tested to understand the effect of binding metal ions to the (L-FSB) ligand. Antimicrobial study indicates that

metal complexes show more inhibition than (L- FSB) ligand.

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Authors' Contributions

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