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Spectral, thermal, molecular modeling and biological studies on mono- and binuclear complexes derived from oxalo bis(2,3-butanedionehydrazone)

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Abstract

Background: Hydrazones and their metal complexes were heavily studied due to their pharmacological applications such as antimicrobial, anticonvulsant analgesic, anti-inflammatory and anti-cancer agents. This work aims to synthesize and characterize novel complexes of VO^{2+} , Co^{2+} , Ni^{2+} , Cu^{2+} , Zn^{2+} , Zr^{4+} and Pd^{2+} ions with oxalo bis(2,3-butanedione-hydrazone). Single crystals of the ligand have been grown and analyzed.

Results: Oxalo bis(2,3-butanedionehydrazone) [OBH] has a monoclinic crystal with P 1 21/n 1 space group. The VO^{2+} , Co^{2+} , Ni^{2+} , Cu^{2+} , Zn^{2+} , Zr^{4+} and Pd^{2+} complexes have the formulas: $[\text{VO}(\text{OBH}-\text{H})_2]\cdot\text{H}_2\text{O}$, $[\text{Co}(\text{OBH})_2\text{Cl}]\text{Cl}\cdot\frac{1}{2}\text{EtOH}$, $[\text{Ni}_2(\text{OBH})\text{Cl}_4]\cdot\text{H}_2\text{O}\cdot\text{EtOH}$, $[\text{Cu}(\text{OBH})_2\text{Cl}_2]\cdot 2\text{H}_2\text{O}$, $[\text{Zn}(\text{OBH}-\text{H})_2]$, $[\text{Zr}(\text{OBH})\text{Cl}_4]\cdot 2\text{H}_2\text{O}$, and $[\text{Pd}_2(\text{OBH})(\text{H}_2\text{O})_2\text{Cl}_4]\cdot 2\text{H}_2\text{O}$. All complexes are nonelectrolytes except $[\text{Co}(\text{OBH})_2\text{Cl}]\text{Cl}\cdot\frac{1}{2}\text{EtOH}$. OBH ligates as: neutral tetradentate (NNOO) in the Ni^{2+} and Pd^{2+} complexes; neutral bidentate (OO) in $[\text{Co}(\text{OBH})_2\text{Cl}]\text{Cl}\cdot\frac{1}{2}\text{EtOH}$, $[\text{Zr}(\text{OBH})\text{Cl}_4]\cdot 2\text{H}_2\text{O}$ and $[\text{Cu}(\text{OBH})_2\text{Cl}_2]\cdot 2\text{H}_2\text{O}$ and monobasic bidentate (OO) in the Zn^{2+} and VO^{2+} complexes. The NMR (^1H and ^{13}C) spectra support these data. The results proved a tetrahedral for the Zn^{2+} complex; square-planar for Pd^{2+} ; mixed stereochemistry for Ni^{2+} ; square-pyramid for Co^{2+} and VO^{2+} and octahedral for Cu^{2+} and Zr^{4+} complexes. The TGA revealed the outer and inner solvents as well as the residual part. The molecular modeling of $[\text{Ni}_2(\text{OBH})\text{Cl}_4]\cdot\text{H}_2\text{O}\cdot\text{EtOH}$ and $[\text{Co}(\text{OBH})_2\text{Cl}]\text{Cl}\cdot\frac{1}{2}\text{EtOH}$ are drawn and their molecular parameters proved that the presence of two metals stabilized the complex more than the mono metal. The complexes have variable activities against some bacteria and fungi. $[\text{Zr}(\text{OBH})\text{Cl}_4]\cdot 2\text{H}_2\text{O}$ has the highest activity. $[\text{Co}(\text{OBH})_2\text{Cl}]\text{Cl}\cdot\frac{1}{2}\text{EtOH}$ has more activity against *Fusarium*.

Conclusion: Oxalo bis(2,3-butanedionehydrazone) structure was proved by X-ray crystallography. It coordinates with some transition metal ions as neutral bidentate; mononegative bidentate and neutral tetradentate. The complexes have tetrahedral, square-planar and/or octahedral structures. The VO^{2+} and Co^{2+} complexes have square-pyramid structure. $[\text{Cu}(\text{OBH})_2\text{Cl}_2]\cdot 2\text{H}_2\text{O}$ and $[\text{Ni}_2(\text{OBH})\text{Cl}_4]\cdot\text{H}_2\text{O}\cdot\text{EtOH}$ decomposed to their oxides while $[\text{VO}(\text{OBH}-\text{H})_2]\cdot\text{H}_2\text{O}$ to vanadium. The energies obtained from molecular modeling calculation for $[\text{Ni}_2(\text{OBH})\text{Cl}_4]\cdot\text{H}_2\text{O}\cdot\text{EtOH}$ are less than those for $[\text{Co}(\text{OBH})_2\text{Cl}]\text{Cl}\cdot\frac{1}{2}\text{EtOH}$ indicating the two metals stabilized the complex more than mono metal. The $\text{Co}(\text{II})$ complex is polar molecule while the $\text{Ni}(\text{II})$ is non-polar.

Keywords: Hydrazones, Spectra, TGA, Biological activity, X-ray crystallography

Background

Hydrazones and their metal complexes are heavily studied compounds which have many pharmacological

applications such as antimicrobial, anticonvulsant analgesic, anti-inflammatory and anti-cancer agents. Acetylpyridine and benzoylpyridine hydrazones were used as reagents against brain tumor and are highly cytotoxic to glioma cells [1]. Interest has been focused on hydrazone

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complexes to study their anti-parasitic, fungicidal and bactericidal properties [2, 3]. 2,3-Butanedione monoxime possessed cardio protective properties related to the inhibition of cross-bridge force development [4]. Heterocyclic compounds containing nitrogen have much attention due to their activity as antitumor, anti-inflammation, anti-pyretic, antiviral, anti-microbial, insecticides and fungicides [5–7]. Isonicotinyl hydrazone complexes of 2-acetylpyridine, pyrrolyl-2-carboxaldehyde, 2,5-dihydroxy-acetophenone, N-isonicotinamido-furfuralimine, 2-thiophenecarbonyl and 3-(N-methyl)-isatin were reported [8–12]. The Ni(II) and Cu(II) complexes of 2,3-butanedione bis(N(3) substituted-thiosemicarbazones) were studied and some of these compounds were solved by x-ray crystallography [13]. The crystal structures of [Cu(HxPip-2H)] (HxPip = 3,4-hexanedione bis(3-piperidylthiosemicarbazone) and [Cu(HxHexim-2H)] (HxHexim = 3,4-hexanedione bis(3-hexa-methyleneiminythiosemicarbazone) were solved having a square-planar geometry [14]. Binuclear complexes of VO²⁺, Co²⁺, Ni²⁺, Cu²⁺ and Zn²⁺ with oxalyl bis(diacetylmonoximehydrazone) were characterized as 2:2 (M:L) and an octahedral geometry for VO²⁺, tetrahedral for Zn²⁺ and square-planar for the rest complexes were proposed [15]. On continuation to our work on bis(hydrazones) and their complexes [16, 17], this work aims to synthesize and characterize novel complexes of VO²⁺, Co²⁺, Ni²⁺, Cu²⁺, Zn²⁺, Zr⁴⁺ and Pd²⁺ ions with oxalo bis(2,3-butanedione-hydrazone). Single crystals for the ligand have been grown and analyzed. Trials to grow crystals for the complexes were failed, so molecular modeling for the Co(II) and Ni(II) complexes were done.

Experimental

VOSO₄·2H₂O, CoCl₂·6H₂O, NiCl₂·6H₂O, CuCl₂·2H₂O, ZnCl₂·2H₂O, K₂PdCl₄ and ZrCl₄, diethyl oxalate, hydrazine hydrate, 2,3-butanedione, ethanol, diethyl ether, DMF and DMSO were obtained from the BDH chemicals.

Synthesis of oxalo bis(2,3-butanedionehydrazone) [OBH]

OBH was prepared by heating under reflux a suspension (6 g, 0.05 mol) of oxalic acid dihydrazide in 50 mL EtOH and 8.6 ml (0.1 mol) of 2,3-butanedione on a heating mantle for 10 h. The precipitate thus formed was filtered off, recrystallized from ethanol and finally dried. It was characterized by elemental analysis and spectral studies. The ¹H NMR spectrum of the ligand showed signals at δ = 11.924 (s, 2H) and 2.129 (s, 6H) ppm for the NH and CH₃ protons. Its ¹³C NMR showed peaks at 196.65, 167.58, 148.81 and 23.90 ppm for (C=O)_{ketonic} (C=O)_{amidic}, C=N and CH₃, respectively.

Preparation of the metal complexes

The metal complexes were prepared by reacting calculated amounts corresponding to 2:1 ratio [M:L] in 50 mL EtOH and the mixture was heated under reflux for 6–8 h. In the preparation of VO²⁺ complex, 0.1 g of sodium acetate was added to raise the pH (~8) and precipitating the complex. The formed precipitates were filtered off, washed with hot water, hot ethanol and diethyl ether and finally dried in a vacuum desiccator over anhydrous silica gel. Attempts to grow single crystals for the complexes were done but unsuccessful.

Analysis and equipment

Carbon, hydrogen and nitrogen content of the compounds were determined at the Microanalytical Unit (Varian Micro V1.5.8, CHNS Mode, 15073036) of Kuwait University. The metal content was determined using ICP-OES GBC Quantum Sequential at Kuwait University. The mass spectra were recorded on a GC-MS ThermoDFS (BG_FAB) mass spectrometer. The melting points were measured on a Griffin melting point apparatus. The conductance for 10⁻³ mol L⁻¹ DMSO solution of the compounds was measured on Orion 3 STAB Conductivity Bridge. The IR spectra were recorded as KBr discs on a FT/IR-6300 type A (400–4000 cm⁻¹). The electronic spectra of the complexes were recorded on a Cary 5 UV-vis spectrophotometer, varian (200–900 nm). The ¹H NMR spectra of the ligand and the diamagnetic complexes were recorded in DMSO-d₆, on a Bruker WP 200 SY Spectrometer (400 MHz) at room temperature using tetramethylsilane (TMS) as an external standard. The magnetic measurements were carried out on a Johnson-Matthey magnetic balance, UK. The TGA thermograms were recorded (25–800 °C) on a Shimadzu TGA-60; the nitrogen flow and heating rate were 50 ml/min and 10 °C min⁻¹, respectively. The X-ray single crystal diffraction data were collected on a Rigaku R-Axis Rapid diffractometer using filtered Mo-K α-radiation. The structure was solved by the direct methods and expanded using Fourier techniques at Kuwait University. The ligand and its complexes were investigated for antimicrobial activity against *Bacillus*, *Aspergillus*, *Escherichia coli*, *Penicillium* and *Fusarium* as reported earlier [15]. All molecular calculations were carried out by HyperChem 7.51 software package. The molecular geometry of the Co²⁺ and Ni²⁺ complexes are first optimized at molecular mechanics (MM+) level. Semi empirical method PM3 is then used for optimizing the full geometry of the system using Polak-Ribiere (conjugate gradient) algorithm and Unrestricted Hartree-Fock (UHF) is employed keeping RMS gradient of 0.01 kcal/Å mol.

Results and discussion

Crystal analysis of OBH

The crystal structure of OBH is shown in Structure 1. Its refinement data are summarized in Table 1 while the bond lengths and bond angles are presented in Table 2. OBH was crystallized as monoclinic system and P 121/n1 space group with molecular weight of 254.25. The N₁–C₃, O₁–C₂ and O₂–C₄ distances are 1.283(3), 1.210(3) and 1.206 Å, respectively, indicating true double bond; the amidic carbonyl has value slightly higher than the ketonic carbonyl. The N₂–C₄ and N₁–N₂ are 1.351(4) and 1.381 Å indicating single bonds. All bond angles are between 115 and 127 and 109.5° meaning the trigonal and tetrahedral geometries with sp² and sp³ hybridization. The presence of lone pair of electrons on N₁ in C₃N₁N₂ reduces the angle from 120° to 115.7°. The bond angle of N₂–C₄–C₄ reduces to 110.6°, in consistent with some distortion, while that of O₂–C₄–N₂ increases to 126.9° due to the existence of two more electronegative atoms (O atoms).

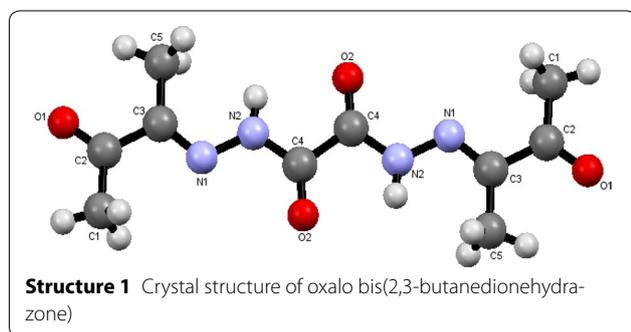


Table 1 Crystallographic data for OBH crystal

| Identification code | OBH |
|------------------------|--|
| Chemical formula | C ₁₀ H ₁₄ N ₄ O ₄ |
| Formula weight | 254.25 |
| Temperature | 296 (2) K |
| Wavelength | 1.54178 Å |
| Crystal size | 0.020 × 0.120 × 0.230 mm |
| Crystal habit | Clear light colorless flakes |
| Crystal system | Monoclinic |
| Space group | P 1 21/n 1 |
| Unit cell dimensions | a = 6.3630 (5) Å, α = 90° b = 4.6609 (4) Å, β = 91.37° c = 20.7562 (19) Å, γ = 90° |
| Volume | 615.40 (9) Å ³ |
| Z | 2 |
| Density (calculated) | 1.372 g/cm ³ |
| Absorption coefficient | 0.915 mm ⁻¹ |
| F (000) | 268 |

Table 2 Bond lengths and bond angles of OBH

| Bond | Length | Bond | Length |
|------------|-----------|------------|-----------|
| O1–C2l | 1.210 (3) | O2–C4 | 1.206 (3) |
| N1–C3 | 1.283 (3) | N1–N2 | 1.381 (3) |
| N2–C4 | 1.351 (4) | N2–H7 | 0.86 |
| C1–C2 | 1.479 (4) | C1–H1 | 0.96 |
| C1–H2 | 0.96 | C1–H3 | 0.96 |
| C2–C3 | 1.506 (4) | C3–C5 | 1.486 (4) |
| C4–C4#1 | 1.529 (6) | C5–H5 | 0.96 |
| C5–H4 | 0.96 | C5–H6 | 0.96 |
| Bond | Angle (°) | Bond | Angle (°) |
| C3–N1–N2 | 115.7 (2) | C4–N2–N1 | 120.6 (2) |
| C4–N2–H7 | 119.7 | N1–N2–H7 | 119.7 |
| C2–C1–H1 | 109.5 | C2–C1–H2 | 109.5 |
| H1–C1–H2 | 109.5 | C2–C1–H3 | 109.5 |
| H1–C1–H3 | 109.5 | H2–C1–H3 | 109.5 |
| O1–C2–C1 | 122.0 (3) | O1–C2–C3 | 117.9 (3) |
| C1–C2–C3 | 120.1 (3) | N1–C3–C5 | 126.6 (3) |
| N1–C3–C2 | 115.0 (3) | C5–C3–C2 | 118.4 (3) |
| O2–C4–N2 | 126.9 (3) | O2–C4–C4#1 | 122.4 (3) |
| N2–C4–C4#1 | 110.6 (3) | C3–C5–H5 | 109.5 |
| C3–C5–H4 | 109.5 | H5–C5–H4 | 109.5 |
| C3–C5–H6 | 109.5 | H5–C5–H6 | 109.5 |
| H4–C5–H6 | 109.5 | | |

Analytical data

The data of CHN and metal contents of the complexes are presented in Table 3. The values confirm mononuclear complexes: [VO(OBH–H)₂].H₂O, [Co(OBH)₂Cl]Cl·½EtOH, [Cu(OBH)₂Cl₂].2H₂O, [Zn(OBH–H)₂], [Zr(OBH)Cl₄].2H₂O and binuclear complexes: [Ni₂(OBH)Cl₄].H₂O·EtOH and [Pd₂(OBH)(H₂O)₂Cl₄].2H₂O. All complexes are colored, solid and stable towards air and moisture at room temperature. They have high melting points and are insoluble in most common organic solvents and completely soluble in DMSO. The molar conductance values (Table 3) of 10⁻³ mol L⁻¹ DMSO solution proved the non-electrolytic nature. The measured value for the Co(II) complex supports the formation of [Co(OBH)₂Cl]⁺Cl⁻·½EtOH [18].

IR and NMR (¹H and ¹³C) spectra

OBH showed the characteristic bands for ν(NH), ν(C=O) [ketonic and amidic] and ν(C=N) vibrations at 3325, 1701 and 1605, respectively in its IR spectrum (Fig. 1a). Inspections of the IR spectral data of the complexes, Table 4, three modes are suggested. The ¹H NMR spectrum showed the NH and CH₃ protons at 11.924 (s, 2H) and 2.129 (s, 6H) ppm, respectively. On the other hand, the ¹³C NMR spectrum have multiple peaks

Table 3 Elemental analysis and some physical properties of OBH and its complexes

| Compound, empirical formula | M.W. (Found, m/e) | Color | M.P. (°C) | Λ (Ohm ⁻¹ cm ² mol ⁻¹) ^a | C % Calcd. (Found) | H % Calcd. (Found) | N % Calcd. (Found) | M % Calcd. (Found) |
|---|-----------------------------|-----------------|-----------|---|--------------------|--------------------|--------------------|--------------------|
| OBH C ₁₀ H ₁₄ N ₄ O ₄ | 254.25 (255.30) | White | 247–249 | 1.76 | 46.66 (47.04) | 5.75 (5.55) | 22.70 (22.34) | – |
| [Co(OBH) ₂ Cl]Cl·½EtOH C ₂₁ H ₃₁ N ₈ O _{8.5} Cl ₂ Co | 661.395 | Pale brown | >325 | 48.0 | 38.13 (38.13) | 4.72 (4.94) | 16.94 (16.68) | 8.91 (8.63) |
| [Zr(OBH)Cl ₄]·2H ₂ O C ₁₀ H ₁₈ N ₄ O ₆ Cl ₄ Zr | 523.33 (523.4) | Pale orange | >325 | 20.10 | 22.95 (22.63) | 3.47 (3.87) | 10.70 (10.79) | 17.70 (17.20) |
| [Zn(OBH–H) ₂] C ₂₀ H ₂₆ N ₈ O ₈ Zn | 571.84 | Yellowish white | >325 | 2.62 | 42.09 (42.49) | 4.58 (5.08) | 19.59 (19.39) | |
| [VO(OBH–H) ₂]·H ₂ O C ₂₀ H ₂₆ N ₈ O ₁₀ V | 591.86 | Brown | 293 | 9.74 | 40.58 (39.99) | 4.77 (4.98) | 18.93 (18.28) | 8.45 (7.93) |
| [Cu(OBH) ₂ Cl ₂]·2H ₂ O C ₂₀ H ₃₂ N ₈ O- 10Cl ₂ Cu | 678.99 | Yellowish green | >325 | 22.50 | 35.37 (35.35) | 4.45 (4.58) | 16.50 (16.07) | 9.34 (9.08) |
| [Ni ₂ (OBH)Cl ₄]·H ₂ O·EtOH C ₂₀ H ₂₂ N ₄ O- 6Cl ₄ Ni ₂ | 577.62 (371.7) ^b | Reddish brown | >325 | 37.30 | 24.95 (24.53) | 3.84 (4.11) | 9.70 (9.39) | 20.34 (20.54) |
| [Pd ₂ (OBH)(H ₂ O) ₂ Cl ₄]·2H ₂ O C ₁₀ H ₂₂ N- 4O ₄ Cl ₄ Pd ₂ | 618.18 (620.30) | Brown | >325 | 24.48 | 20.63 (20.96) | 3.81 (4.20) | 9.62 (9.39) | |

^a Molar conductance values for 0.001 mol L⁻¹ DMSO solution

^b The value represents Ni(OBH)Cl·½EtOH

corresponding to (C=O)_{ketonic}, (C=O)_{amidic}, C=N and CH₃ groups at 196.65, 167.58, 148.81 and 23.90 ppm.

In the first mode, OBH acts as a neutral bidentate ligand in [Co(OBH)₂Cl]Cl·½EtOH (Structure 2), [Cu(OBH)₂Cl₂]·2H₂O and [Zr(OBH)Cl₄]·2H₂O coordinating through the two amidic carbonyl groups based on the following observations: the ν (C=O) band observed at 1701 cm⁻¹ in ligand spectrum was shifted to 1686–1699 cm⁻¹ in complexes having little intensity indicating that the two amidic carbonyl groups (C=O)_{amidic} participated in bonding while the other two carbonyl (C=O)_{ketonic} still at the same position. The new band at 464–495 cm⁻¹ is due to ν (M–O) vibration [19]. The ν (C=N) at 1605 cm⁻¹ appeared very weak, less intensity with little shift to higher wavenumber in the Co(II) and Cu(II) complexes and to lower wavenumber in the Zr(IV) complex (1585 cm⁻¹).

In the second mode, OBH acts as a mononegative bidentate in Zn²⁺ and VO²⁺ complexes coordinating through the two amidic carbonyl (enolic form), from each ligand molecule. The shift of ν (C=O) to lower or higher wavenumbers with appearance of ν (C=N)*, ν (C–O) (due to enolization of one amidic group) [20] and ν (M–O) at 1550, 1140 and 463 cm⁻¹ indicates the participation of carbonyl group in bonding. In the VO²⁺ complex, the band observed at 3412 cm⁻¹ is attributed to hydrated water [21] and absence of sulfate bands indicates enol type of complexes. The ¹H NMR spectrum of [Zn(OBH–H)₂] showed splitting of NH signal as a result of conversion of one of NHC=O to N=C–OH and the existence of the others without participation (Structure 3). The signals of CH₃ protons appeared at the same position as in ligand spectrum. In its ¹³C NMR, peaks of both ketonic and amidic groups still at the same position with

appearance of a new one at 166.21 ppm although one of the C=O)_{amidic} changed to enol form. Also, the appearance of C=N as doublet peak in 149.44–148.44 ppm range confirming enolization. In the ¹³C NMR spectrum of VO²⁺ complex, the peaks at 172.50, 168.44–167.47, 149.60–148.86, 124.68 and 24.98–24.30 ppm are due to (C=O)_{ketonic}, (C=O)_{amidic} free, (C=O)_{amidic} bonded, (C=N), (C=N)*, (C–O) and CH₃, respectively. The appearance of (C=N)* (due to conversion of NHC=O to N*=C–O) and (C–O) peaks confirm enolization process (Table 5).

The third mode confirmed neutral tetradentate but with two metal ions in [Ni₂(OBH)Cl₄]·H₂O·EtOH (Structure 4) and [Pd₂(OBH)(H₂O)₂Cl₄]·2H₂O (Fig. 1b, c). The coordination sites are two azomethine nitrogens of the hydrazone moiety and two carbonyl groups of amidic moiety; each two donors chelated one metal ion. The shift of ν (C=N) to 1542 cm⁻¹ and ν (C=O)_{amidic} to 1644 in the Pd(II) complex and to 1552 and 1676 in the Ni(II) complex together with appearance of ν (M–N) [22] and ν (M–O) bands at ~465 and ~540 cm⁻¹, respectively. In the Ni(II) complex, the band of carbonyl groups splitted to two at 1697 and 1676 cm⁻¹; the first is due to ketonic group which is not participated in bonding. The NH band appeared very weak in Ni(II) complex and very broad in Pd(II) complex. Finally, the band at 3389 or 3441 cm⁻¹ in Ni(II) or Pd(II) complex is due to hydrated water or ethanol.

Mass spectra

The data of FAB-mass spectra of OBH and some of its complexes are shown in Table 3. The mass spectrum of OBH showed the molecular ion peak (base peak) at m/z = 255.30 (Calcd. 254.25) corresponding to

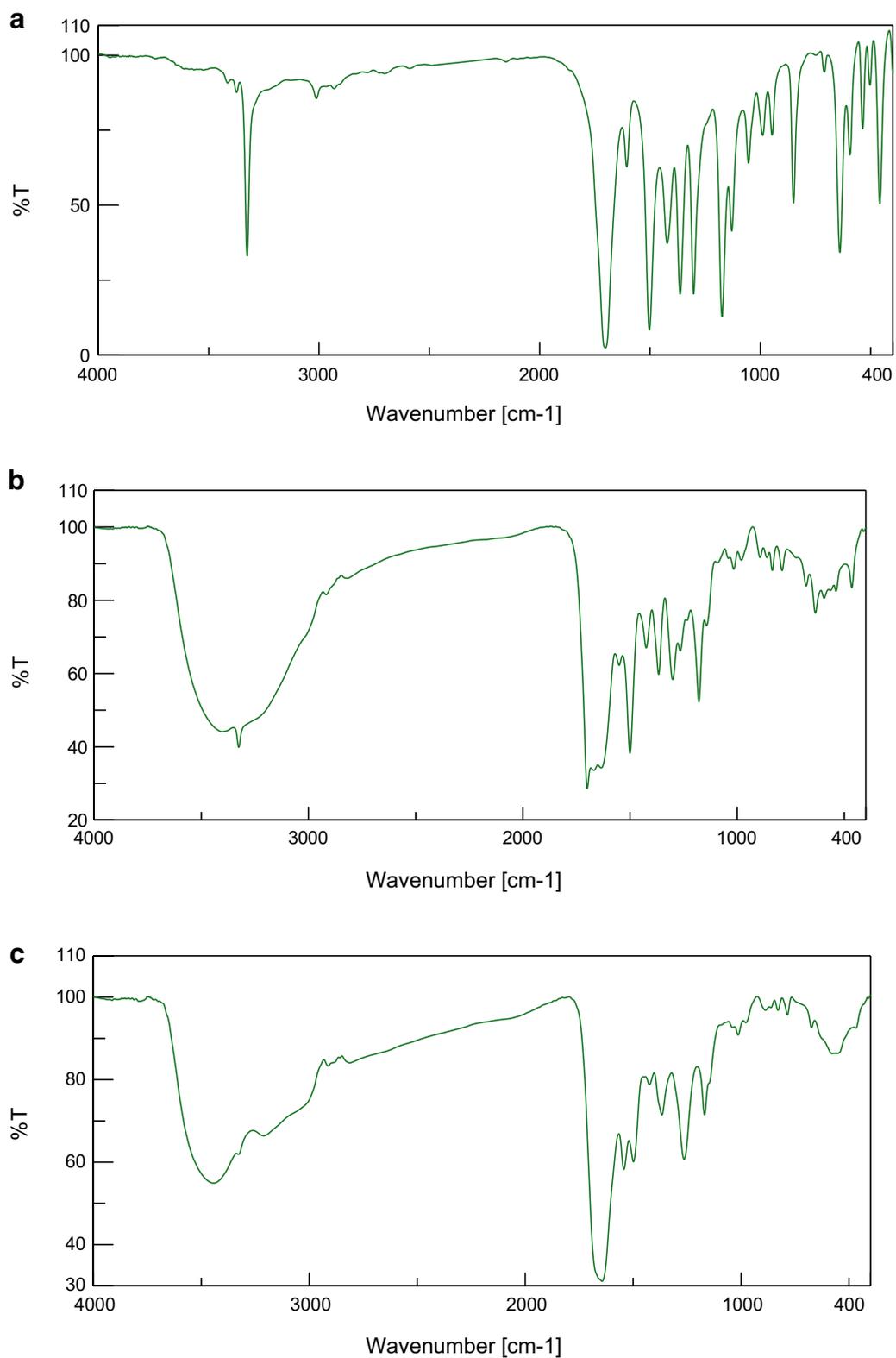
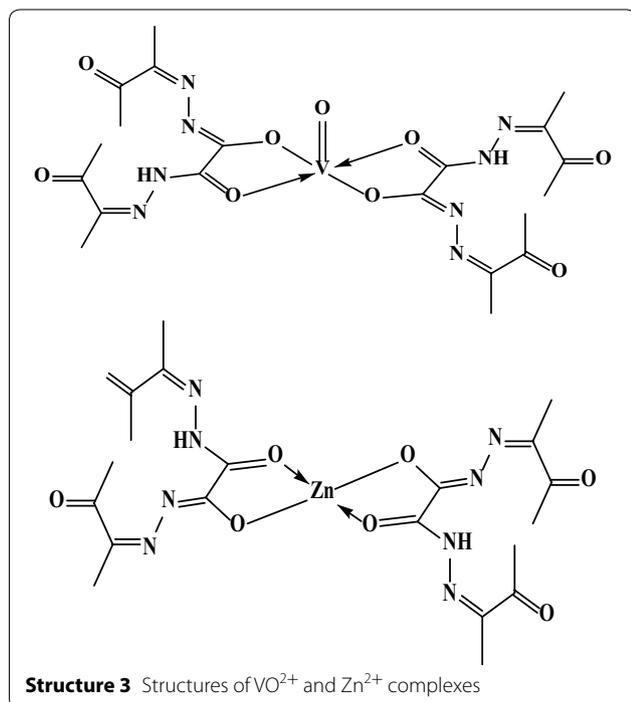
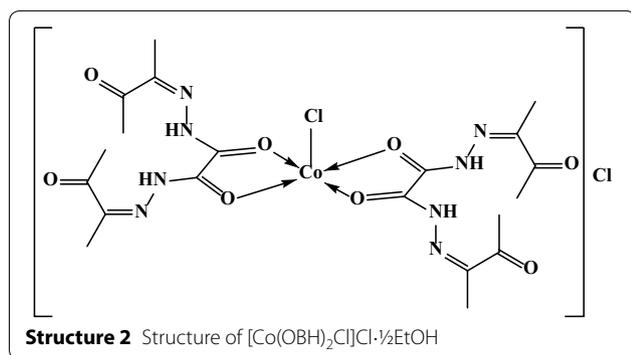


Fig. 1 IR spectra of OBH (a); [Ni₂(OBH)Cl₄]·H₂O·EtOH (b) and [Pd₂(OBH)Cl₄]·6H₂O (c)

Table 4 IR band assignments of OBH and its complexes

| Compound | $\nu(\text{NH})$ | $\nu(\text{C}=\text{O})$ | $\nu(\text{C}=\text{N})$ | $\nu(\text{C}=\text{N})^a$ | $\nu(\text{C}-\text{O})$ | $\nu(\text{M}-\text{O})$ | $\nu(\text{M}-\text{N})$ | Observations |
|---|-------------------------|--------------------------|--------------------------|----------------------------|--------------------------|--------------------------|--------------------------|--|
| OBH | 3325 (s) | 1701 (s) | 1605 (m) | – | – | – | – | |
| $[\text{Co}(\text{OBH})_2\text{Cl}]\text{Cl}\cdot\frac{1}{2}\text{EtOH}$ | 3325 (m) | 1699 (s) | 1612 (w) | – | – | 464 (m) | – | 3415 (br) for EtOH |
| $[\text{Zr}(\text{OBH})\text{Cl}_4]\cdot 2\text{H}_2\text{O}$ | 3326 (vbr) ^a | 1686 (m) | 1585 (m) | – | – | 495 (br) | – | |
| $[\text{Zn}(\text{OBH}-\text{H})_2]$ | – | 1699 (s) | 1605 (w) | 1550 (w) | 1140 (w) | 463 (s) | – | |
| $[\text{VO}(\text{OBH}-\text{H})_2]\cdot\text{H}_2\text{O}$ | – | 1696 (s) | 1608 (w) | 1552 (w) | 1142 (w) | 463 (m) | – | 3412 (br) for H_2O ; $\nu(\text{V}=\text{O})$ at 961 |
| $[\text{Cu}(\text{OBH})_2\text{Cl}_2]\cdot 2\text{H}_2\text{O}$ | 3325 (m) | 1701 (s) | 1610 (br) | – | – | 464 (m) | – | 3415 (br) for H_2O |
| $[\text{Ni}_2(\text{OBH})\text{Cl}_4]\cdot\text{H}_2\text{O}\cdot\text{EtOH}$ | 3324 | 1676 (br) | 1552 (sh) | – | – | 464 (m) | 539 | 3389 (br) for H_2O |
| $[\text{Pd}_2(\text{OBH})(\text{H}_2\text{O})_2\text{Cl}_4]\cdot 2\text{H}_2\text{O}$ | 3327 (w) | 1644 | 1542 | – | – | 467 | 542 | 3441 (br) for H_2O |

^a The value for NH and H_2O



$\text{C}_{10}\text{H}_{14}\text{N}_4\text{O}_4$. The peaks shown at 212.2, 190.2, 130.2 and 73.1 are due to $\text{C}_8\text{H}_{11}\text{N}_4\text{O}_3$, $\text{C}_7\text{H}_{11}\text{N}_3\text{O}_3$, $\text{C}_4\text{H}_5\text{N}_3\text{O}_2$ and C_2NO_2 .

The mass spectrum of $[\text{Zr}(\text{OBH})\text{Cl}_4]\cdot 2\text{H}_2\text{O}$ exhibits m/z value of 523.5 (Calcd. 523.33) with 12 % intensity. The value corresponds to $\text{C}_{10}\text{H}_{18}\text{N}_4\text{O}_6\text{Cl}_4\text{Zr}$. Multi-peaks were observed ending with a peak at 69.0 (78 % intensity) may corresponding to 6 C.

Moreover, the mass spectrum of $[\text{Ni}_2(\text{OBH})\text{Cl}_4]\cdot\text{H}_2\text{O}\cdot\text{EtOH}$ has a value of 371.7 (the base peak) corresponding to $\text{Ni}(\text{OBH})\text{Cl}\cdot\frac{1}{2}\text{EtOH}$ meaning that this species is highly stable. Multi peaks were observed ending with one at 128.9 (intensity 65 %) due to ZrO_2 .

Magnetic moments and electronic spectra

The electronic spectral bands of the complexes as well as the magnetic moment values are presented in Table 6. The DMSO solutions of complexes have the same color as in the solid complexes. OBH exhibits one absorption band at $38,460\text{ cm}^{-1}$ collectively due to $\pi \rightarrow \pi^*$ transitions of $\text{C}=\text{N}$, $\text{C}=\text{O}_{\text{ketonic}}$ and $\text{C}=\text{O}_{\text{amidic}}$ groups [23]. The broadness of the band may be due to existence of these groups in opposite sides. The two bands at 25,510 and $23,810\text{ cm}^{-1}$ in Cu(II) complex may be due to $\text{N} \rightarrow \text{MCT}$ and $\text{O} \rightarrow \text{MCT}$ [24]. The Ni(II) complex has only one band at $28,330\text{ cm}^{-1}$ due to $\text{N} \rightarrow \text{MCT}$ while Co(II) and Zr(IV) have also one band but at 23,320 and $22,830\text{ cm}^{-1}$, respectively, due to $\text{O} \rightarrow \text{MCT}$.

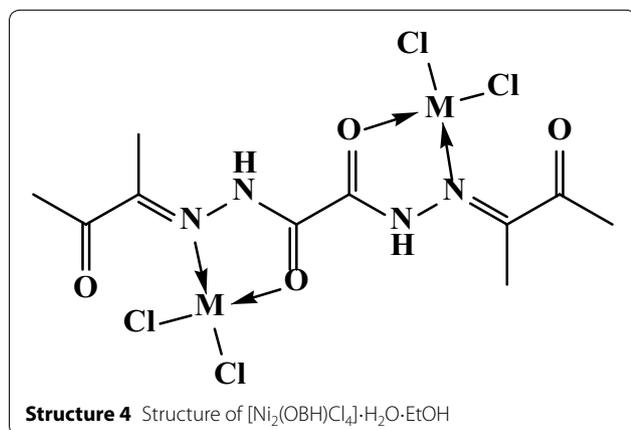
$[\text{Co}(\text{OBH})_2\text{Cl}]\text{Cl}\cdot\frac{1}{2}\text{EtOH}$ (pale brown) has 2.51 BM magnetic moment which lies within the values reported for one unpaired electron of square-planar or square-pyramid Co(II) complexes [25] having dsp^2 or dsp^3 hybridization. Evidence is electronic spectrum which showed one band at $15,250\text{ cm}^{-1}$ with molar extension coefficient of $94\text{ mol}^{-1}\text{ L}$. The spectrum resembled the spectra of the five-coordinate Co(II) complexes [26] and the square-pyramid is the suggested geometry.

The magnetic moment value, for each atom, in $[\text{Ni}_2(\text{OBH}-2\text{H})\text{Cl}_4]\cdot\text{H}_2\text{O}\cdot\text{EtOH}$ is 1.36 BM which is less than the normal values reported for tetrahedral or octahedral coordination containing two unpaired electrons. Its electronic spectrum showed a broad band at

Table 5 ^1H and ^{13}C NMR signals of OBH and its diamagnetic complexes

| Compound | NH | CH ₃ | ^{13}C signals |
|---|----------------------------------|--------------------------------|--|
| OBH | 11.924 (s, 2H) | 2.129 (s, 6H) | 196.65 (C=O) _{ketonic} 167.58; (C=O) _{amidic} 148.81 (C=N) 23.90 (CH ₃) |
| [Zn(OBH-H) ₂] | 11.781 (s, 1H) 11.565 (s, 1H) | 2.371 (s, 3H) 2.118 (s, 3H) | 196.68 (C=O) _{ketonic} 168.02 (C=O) _{amidic} free 166.21 (C=O) _{amidic} bonded 149.44 (C=N), (C=N)* 23.94 (CH ₃) |
| [VO(OBH-H) ₂].H ₂ O | 11.769 (s, 1H) | 2.087 (s, 3H) 2.053 (s, 3H) | 197.12 (C=O) _{ketonic} 172.50 (C=O) _{amidic} (free) 168.44–167.47 (C=O) _{amidic} (bonded) 149.60–148.86 (C=N), (C=N)* 124.68 (C–O) 24.68; 24.98 (CH ₃) |
| [Pd ₂ (OBH)(H ₂ O) ₂ Cl ₄].2H ₂ O | 11.766 (s, 1H) 11.566 (s, 1H) | 2.290 (s, 6H) | 196.75 (C=O) _{ketonic} 167.98; (C=O) _{amidic} 148.88 (C=N) 22.90 (CH ₃) |

*New azomethine group as a result of enolization



$19,050\text{ cm}^{-1}$ ($\epsilon = 180\text{ mol}^{-1}\text{ L}$) typical of a square-planar structure with some distortion [26] may be of tetrahedral; the anomalous magnetic value is consistent with mixed stereochemistry (square-planar + tetrahedral) around the two nickel ions [27]. On the other hand, the diamagnetic nature of $[\text{Pd}_2(\text{OBH})(\text{H}_2\text{O})_2\text{Cl}_4]\cdot 2\text{H}_2\text{O}$ proved the square-pyramid structure in which the metal is surrounded by NO donors, two chloro and one coordinated water. The bands at $37,540$ and $28,470\text{ cm}^{-1}$ are attributed to charge transfer transitions, probably $\text{O} \rightarrow \text{Pd}$ transition [28].

The electronic spectrum of $[\text{Cu}(\text{OBH})_2\text{Cl}_2]\cdot\text{H}_2\text{O}$ exhibits one band with maximum at 20080 cm^{-1} assigned to the $^2\text{E}_{2g} \rightarrow ^2\text{T}_{2g}$ transition in an octahedral geometry [29]. The band is broad due to the Jahn-Teller effect which enhances the distortion of the octahedral geometry generally important for odd number occupancy of

the e_g level. The magnetic moment value (1.45 BM) was found lower than the values reported for the d^9 -system containing one unpaired electron (1.73–2.25 BM) suggesting interactions between the copper centers.

Thermal analysis

The decomposition steps, the DTG maximum temperature and the removing species are shown in Table 7. The thermogram of $[\text{Co}(\text{OBH})_2\text{Cl}]\text{Cl}\cdot\frac{1}{2}\text{EtOH}$ showed three decomposition steps at mid- points of 60 , 319 and $500\text{ }^\circ\text{C}$ corresponding to the removal of $\frac{1}{2}\text{Cl}_2 + \frac{1}{2}\text{EtOH}$ (Found 6.36 %; Calcd. 8.84 %); $\text{C}_{16}\text{H}_{24}\text{N}_4\text{O}_6\text{Cl}$ (Found 60.45 %; Calcd. 61.05 %) and $\text{C}_4\text{H}_4\text{N}_2$ (Found 11.77 %; Calcd 12.11 %) leaving $[\text{CoO}_4\text{N}_2]$ moiety (Found 21.58 %; Calcd. 22.82 %).

The TG curve of $[\text{VO}(\text{OBH}-\text{H})_2]\cdot\text{H}_2\text{O}$ showed also three steps; the first (mid. point $56\text{ }^\circ\text{C}$) represents the removal of the outside water molecule (Found 3.65 %; Calcd 3.04 %); the second (mid. point $289\text{ }^\circ\text{C}$) represents the loss of $\text{C}_{16}\text{H}_{24}\text{N}_4\text{O}_6$ (Found 61.57 %; Calcd 62.24 %) and the third for the repulsion of $\text{C}_4\text{H}_4\text{N}_4\text{O}_2$ (Found 25.56 (Calcd. 23.67 %). The residue is vanadium metal (Found 7.45; Calcd 8.53 %).

$[\text{Cu}(\text{OBH})_2\text{Cl}_2]\cdot 2\text{H}_2\text{O}$ thermogram showed decomposition steps ending with copper oxide at Temp. $>400\text{ }^\circ\text{C}$. The decomposition showed the removal of the two hydrated water in the first step at mid. point of $59\text{ }^\circ\text{C}$. The other two steps were observed at 291 and $374\text{ }^\circ\text{C}$ corresponding to the removal of $\text{C}_{16}\text{H}_{24}\text{N}_4\text{O}_6$ and $\text{C}_4\text{H}_4\text{N}_4\text{O}_3$, respectively, leaving CuO as a residue.

The TG curve of $[\text{Ni}_2(\text{OBH})\text{Cl}_4]\cdot\text{H}_2\text{O}\cdot\text{EtOH}$ showed four steps. The first at $72\text{ }^\circ\text{C}$ is due to the removal of

Table 6 Magnetic moments, electronic spectra and molar extension coefficient of OBH and its complexes

| Compound | μ_{eff} (BM) | Intraligand and charge transfer transition, cm^{-1} (* ϵ) | d-d transition cm^{-1} (* ϵ) | Proposed structure |
|---|-------------------------|--|---|-----------------------------|
| OBH | – | 38,460 (790) | – | |
| [Co(OBH) ₂ Cl]Cl·½EtOH | 2.51 | 37,450 (195.8); 23,320 (115.8) | 15,250 (94) | Square-pyramid |
| [Zr(OBH)Cl ₄]·2H ₂ O | – | 36,495 (399); 22,830 (117.6) | – | Octahedral |
| [Zn(OBH–H) ₂] | – | 37,450 (530); 35,335 (885) | – | Tetrahedral |
| [VO(OBH–H) ₂]·H ₂ O | 0.00 | 38,060; 35,040; 29,210 | | Square-pyramid |
| [Cu(OBH) ₂ Cl ₂]·2H ₂ O | 1.45 | 39,840; 37,590; 25,510; 23,810 (350) | 20,080 | Octahedral |
| [Ni ₂ (OBH)Cl ₄]·H ₂ O·EtOH | 1.36 ^a | 39,840; 37,590; 28,330 | 19,050 | Square-planar + tetrahedral |
| [Pd ₂ (OBH)(H ₂ O) ₂ Cl ₄]·2H ₂ O | 0.00 | 37,540; 28,470 | 21,500 (310) | Square-pyramid |

* ϵ is the molar extension coefficient (mol^{-1} L)

^a The value per one nickel atom

Table 7 Decomposition steps of the complexes based on the thermogravimetric data

| Complex | DTG maximum temp. (°C) | Removing species | Weight loss % Found (Calcd) |
|---|------------------------|---|-----------------------------|
| [Co(OBH) ₂ Cl]Cl·½EtOH | 60 | - ½Cl ₂ + ½EtOH | 6.36 (8.84) |
| | 319 | - C ₁₆ H ₂₄ N ₄ O ₆ Cl | 60.45 (61.05) |
| | 500 | - C ₄ H ₄ N ₂ | 11.77 (12.11) |
| | >500 | [CoO ₄ N ₂] (residue) | 21.58 (22.82) |
| [Zr(OBH)Cl ₄]·2H ₂ O | 76 | -(Cl ₂ + H ₂ O) | 16.12 (16.99) |
| | 313 | -(H ₂ O + C ₈ H ₁₂ N ₂ O ₂) | 37.67 (35.58) |
| | 449 | - Cl ₂ | 12.44 (13.55) |
| | >500 | C ₂ N ₂ O ₂ Zr (residue) | 30.15 (33.67) |
| [VO(OBH–H) ₂]·H ₂ O | 59 | - H ₂ O | 3.65 (3.04) |
| | 289 | - C ₁₆ H ₂₄ N ₄ O ₆ | 61.57 (62.24) |
| | 405–590 | - C ₄ H ₄ N ₄ O ₂ | 25.56 (23.67) |
| | >600 | V (residue) | 7.45 (8.53) |
| [Cu(OBH) ₂ Cl ₂]·2H ₂ O | 59 | - 2H ₂ O | 4.29 (5.31) |
| | 291 | - C ₁₆ H ₂₄ N ₄ O ₆ | 54.90 (54.26) |
| | 374 | - C ₄ H ₄ N ₄ O ₃ | 25.56 (26.37) |
| | >400 | CuO (residue) | 12.30 (11.71) |
| [Ni ₂ (OBH)Cl ₄]·H ₂ O·EtOH | 72 | -(EtOH + H ₂ O) | 13.51 (11.08) |
| | 368 | -(Cl ₂ + C ₈ H ₁₂ N ₂ O ₂) | 40.20 (41.40) |
| | 470 | - Cl ₂ | 11.20 (12.27) |
| | 550 | - C ₂ H ₂ N ₂ | 8.00 (9.35) |
| | >600 | 2 NiO (residue) | 27.09 (25.87) |
| [Pd ₂ (OBH)(H ₂ O) ₂ Cl ₄]·2H ₂ O | 75 | - 2H ₂ O | 6.47 (5.83) |
| | 322 | - 2H ₂ O + 2Cl ₂ + C ₄ H ₁₂ | 38.49 (38.48) |

the outside water and EtOH (Found 13.51 %; Calcd. 11.08 %). The second step (368 °C) represents the loss of Cl₂ + C₈H₁₂N₂O₂ (Found 40.20 %; Calcd 41.40 %). The third step represents the repulsion of Cl₂ (Found 11.20 %; Calcd. 12.27 %). The fourth step (Found 8.00 %; Calcd.

9.35 %) corresponding to the removal of C₂H₂N₂. The residue is 2NiO (Found 27.09 %; Calcd. 25.87 %) (Fig. 2).

The thermogram of [Zr(OBH)Cl₄]·2H₂O has C₂N₂O₂Zr as remaining residue above 500 °C with 30.15 % (Calcd. 33.67 %). The first three steps observed at mid. points of 76, 313 and 449 °C are corresponding to the removal of (Cl₂ + H₂O); (H₂O + C₈H₁₂N₂O₂) and Cl₂, respectively (Fig. 3).

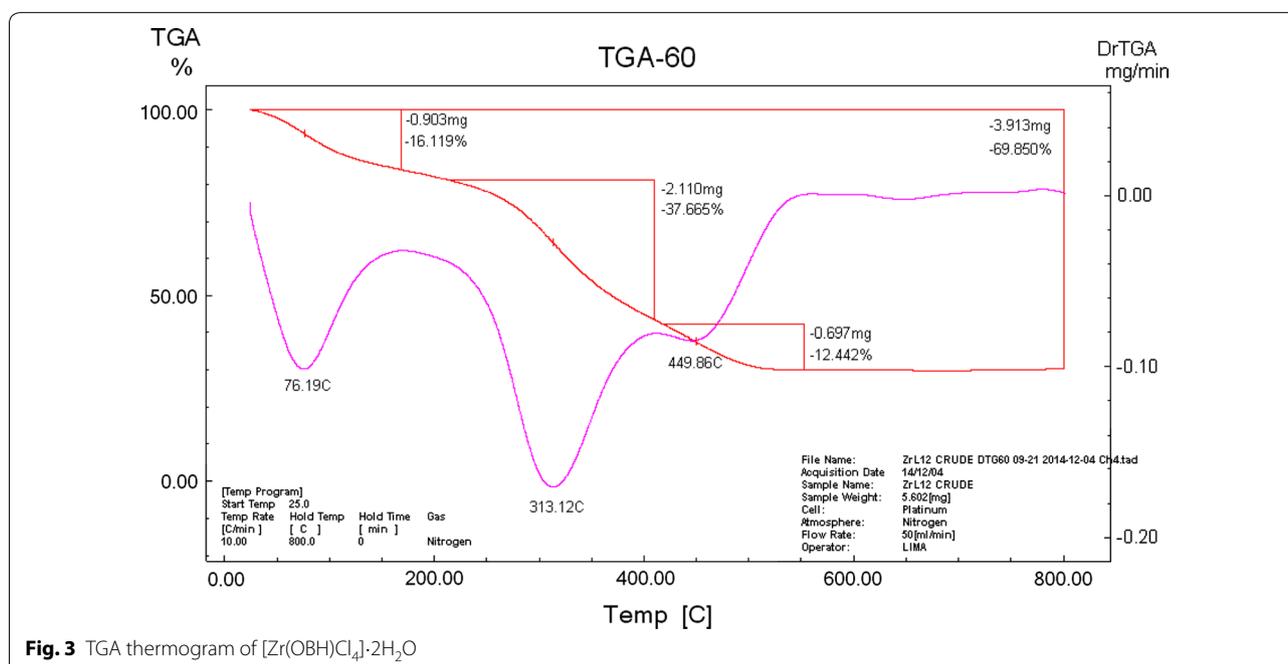
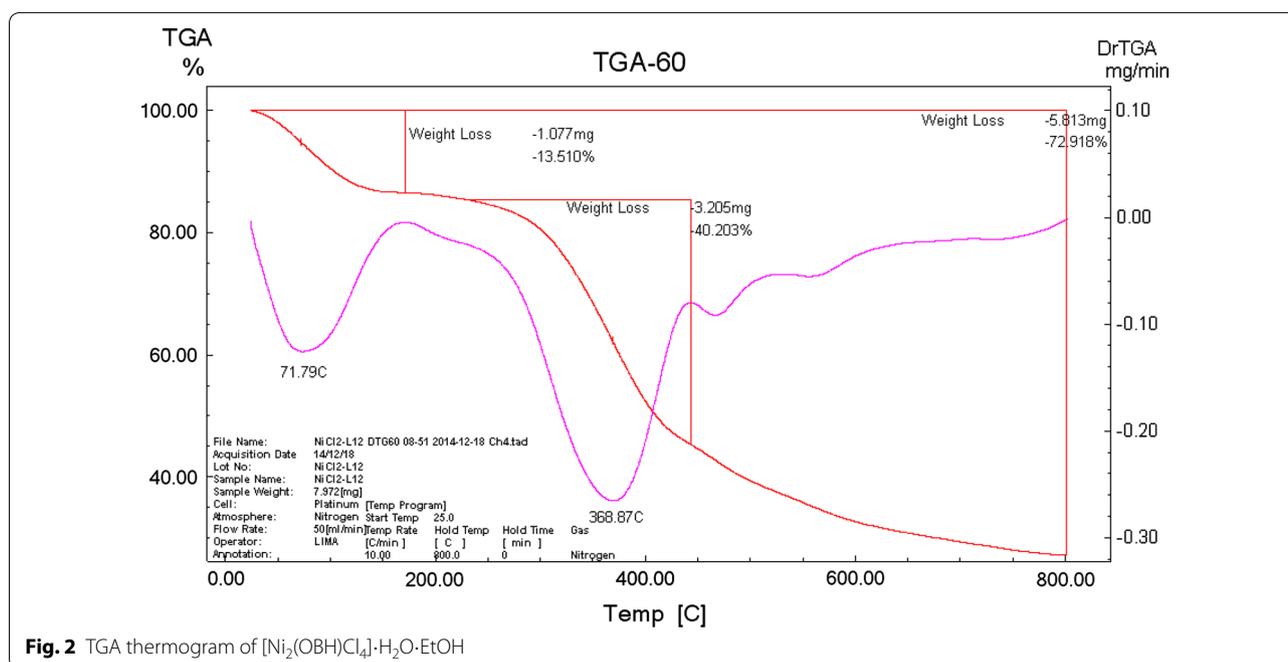
The thermogram of [Pd₂(OBH)(H₂O)₂Cl₄]·2H₂O showed two main steps at 75 and 322 °C due to the liberation of the outside water and 2H₂O + 2Cl₂ + C₄H₁₂, respectively. High residue % was found over 500 °C.

Molecular modeling

Trials to grow single crystals for the investigated complexes were failed. In order to calculate the molecular parameters, [Co(OBH)₂Cl]Cl·½EtOH and [Ni₂(OBH)Cl₄]·H₂O·EtOH (Structure 5) are chosen and their data are presented in Table 8. The bond lengths and the bond angles are shown in Additional file 1: Tables S1 and S2. It is obvious that the energy values obtained for [Ni₂(OBH)Cl₄]·H₂O·EtOH are less than those of [Co(OBH)₂Cl]Cl·½EtOH indicating that the presence of two metals stabilized the complex more than the mono metal lowering the energy. The dipole moment calculated for the Co(II) complex is 4.949 D proving the polar nature of the complex. The value of Ni(II) complex is 0.413 D indicating its non-polarity.

Biological activity

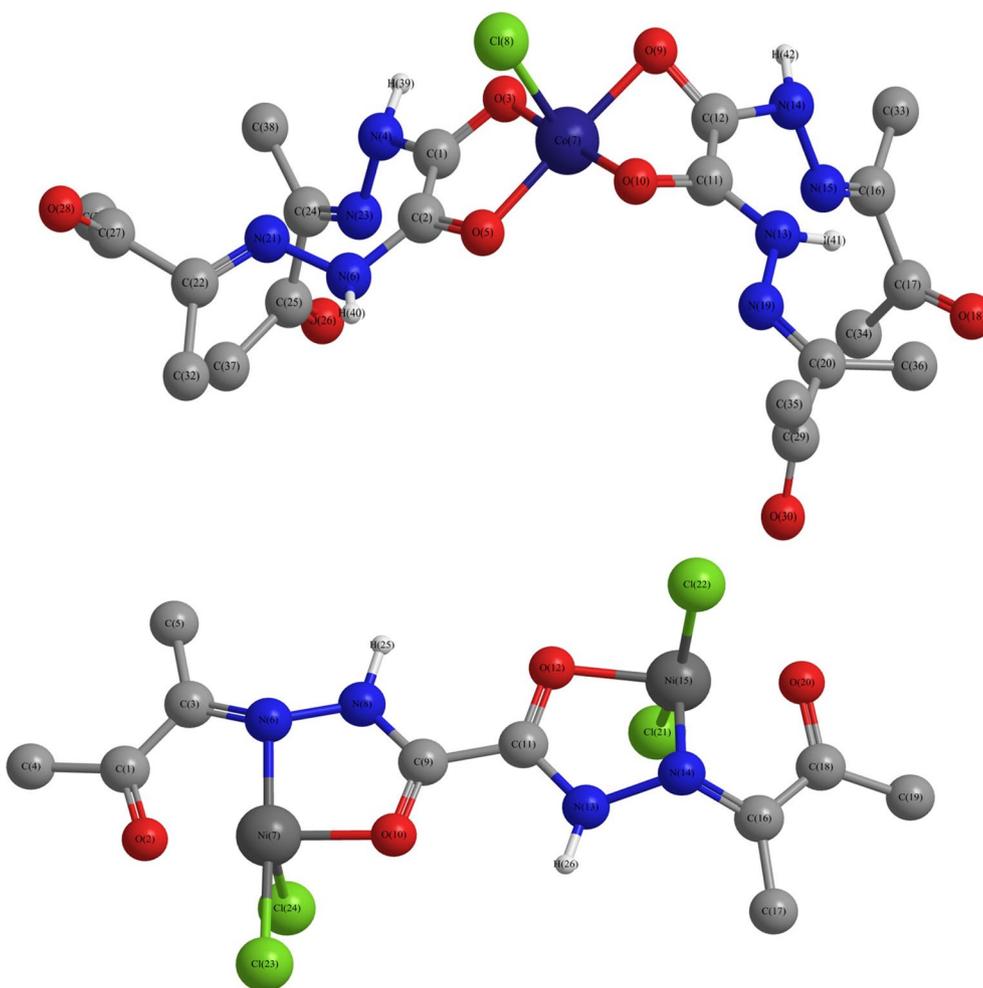
The antimicrobial activity of the metal complexes depends on the following factors: the chelate effect, i.e., bidentate ligands show higher antimicrobial activity than monodentate; the nature of the ligands; the total charge of the complex: cationic > neutral > anionic; the nature of the counter ion and the nuclearity of the metal center: binuclear are more active than mononuclear ones.



It depends more on the metal center itself than on the geometry around the metal ion.

The antimicrobial activities of OBH and its complexes are examined against *Bacillus*, *E. coli*, *Aspergillus*, *Penicillium* and *Fusarium* and the data are given in Table 9. The data showed that $[\text{Zr}(\text{OBH})\text{Cl}_4]\cdot 2\text{H}_2\text{O}$ has higher activity against all tested microorganisms except *E. coli*. The activity is highest and more with *Penicillium*

(9 mm zone inhibition). The higher activity may be due the presence of non-ionizable chlorine and to the less planarity of the complex making it more lipophilic. Most compounds have high activity against *Fusarium*. $[\text{Cu}(\text{OBH})_2\text{Cl}_2]\cdot 2\text{H}_2\text{O}$ has higher value against *Fusarium* (15 mm). Comparing these data with that of ampicillin and those obtained for different hydrazone complexes showed more or less activity [29, 30].



Structure 5 Molecular modeling of $[\text{Co}(\text{OBH})_2\text{Cl}]\text{Cl}\cdot\frac{1}{2}\text{EtOH}$ and $[\text{Ni}_2(\text{OBH})\text{Cl}_4]\cdot\text{H}_2\text{O}\cdot\text{EtOH}$

Table 8 Molecular parameters of the Co(II) and Ni(II) complexes

| Parameter | $[\text{Co}(\text{OBH})_2\text{Cl}]\text{Cl}\cdot\frac{1}{2}\text{EtOH}$ | $[\text{Ni}_2(\text{OBH})\text{Cl}_4]\cdot\text{H}_2\text{O}\cdot\text{EtOH}$ |
|-----------------------------------|--|---|
| Total energy (kcal/mol) | -174051.6072885 | -151380.5229794 |
| Total energy (a.u.) | -277.368857336 | -241.240189251 |
| Binding energy (kcal/mol) | -6649.8942255 | -3610.0626914 |
| Isolated atomic energy (kcal/mol) | -167401.7130630 | -147770.4602880 |
| Electronic energy (kcal/mol) | -1559859.4974432 | -935598.9682580 |
| Core-core interaction (kcal/mol) | 1385807.8901548 | 784218.4452785 |
| Heat of formation (kcal/mol) | -261.3762255 | -159.9386914 |
| Gradient (kcal/mol/Å) | 53.4569309 | 42.0607388 |
| Dipole (Debyes) | 4.949 | 0.413 |

Conclusion

Oxalo bis(2,3-butanedionehydrazone) has been prepared and characterized by x-ray crystallography. It coordinates as neutral bidentate; mononegative bidentate and neutral tetradentate. The complexes have tetrahedral, square-planar and/or octahedral structures. The VO^{2+} and Co^{2+} complexes have square-pyramidal structure. $[\text{Cu}(\text{OBH})_2\text{Cl}_2]\cdot 2\text{H}_2\text{O}$ and $[\text{Ni}_2(\text{OBH})\text{Cl}_4]\cdot\text{H}_2\text{O}\cdot\text{EtOH}$ decomposed to their oxides while $[\text{VO}(\text{OBH}-\text{H})_2]\cdot\text{H}_2\text{O}$ to the metal. The energies from molecular modeling calculation is less in $[\text{Ni}_2(\text{OBH})\text{Cl}_4]\cdot\text{H}_2\text{O}\cdot\text{EtOH}$ than those for $[\text{Co}(\text{OBH})_2\text{Cl}]\text{Cl}\cdot\frac{1}{2}\text{EtOH}$ indicating that the presence of two metals stabilized the complex more than the mono metal. The Co(II) complex is polar molecule while the Ni(II) is non-polar.

Table 9 Effect of ligand and its complexes on some micro-organisms

| Compound | <i>Bacillus</i> | <i>E. coli</i> | <i>Aspergillus</i> | <i>Penicillium</i> | <i>Fusarium</i> |
|--|-----------------|----------------|--------------------|--------------------|-----------------|
| OBH | Nil | 2.0 | Nil | Nil | Nil |
| [Co(OBH) ₂ Cl] Cl·½EtOH | Nil | 1.0 | Nil | Nil | 15 |
| [Zr(OBH)Cl ₄ ·2H ₂ O | 10 | Nil | 4.0 | 9.0 | 8.0 |
| [Zn(OBH-H) ₂] | Nil | 1.0 | Nil | Nil | 5.0 |
| [Cu(OBH) ₂ Cl ₂ ·2H ₂ O | Nil | 2.0 | Nil | 5.0 | Nil |
| [Ni ₂ (OBH) Cl ₄ ·H ₂ O·EtOH | Nil | 2.0 | Nil | Nil | Nil |
| [Pd ₂ (OBH) (H ₂ O) ₂ Cl ₄ ·2H ₂ O | Nil | Nil | Nil | Nil | 5.0 |
| [VO(OBH-H) ₂ ·H ₂ O | Nil | Nil | Nil | Nil | 5.0 |
| DMSO | Nil | Nil | Nil | Nil | Nil |
| Ampicillin | 25 | – | 27 | – | – |
| Gentamicin | – | 48 | 20 | 25.9 | – |

Reading in diameter (mm)

Further materials

Crystallographic data for the structure reported in this paper have been deposited with Cambridge Crystallographic Data Center as supplementary publication CCDC-985982.

Additional file

Additional file 1: Table S1. Bond lengths and bond angles of the Ni(II) complex. **Table S2.** Bond lengths and bond angles of the Co(II) complex.

Authors' contributions

MA and AES do the experimental part; AEA and BJ interpreted the results and wrote the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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