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ORIGINAL PAPER

Synthesis, characterization and crystal structures of new Zinc(II) and Nickel(II) complexes containing morpholine moiety and their antibacterial studies

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Abstract The ligand 1,2-dimorpholinoethane (DME) was used to prepare Zn(II) and Ni(II) complexes of the general formulation MLX_2 (L = DME, X = Cl or NO_3). Zinc(II) complex exhibits spectral properties indicative of a distorted tetrahedral geometry, with DME coordinating through two nitrogen atoms and two chlorides completing the tetrahedron. This is in contrast to the six-coordinated, distorted octahedral geometry exhibited by nickel(II) complex of DME when NO_3 was used as counter ions. The X-ray diffraction confirms the structures of two complexes and shows that the ligand coordinates through two nitrogen atoms while the two ether linkages are not involved in complexation, which would have been the case if the morpholine rings were in the boat form. The ligand and related complexes have antibacterial activity against the five Gram-positive bacteria: *Bacillus subtilis* ATCC 6633, *Staphylococcus aureus* ATCC 6538, *Bacillus cereus* NRRL-B-3711, *Enterococcus faecalis* ATCC 29212 and *Streptococcus pyogenes* and also against the three Gram-negative bacteria: *Escherichia coli* ATCC 11230, *Pseudomonas aeruginosa* ATCC 15442 and *Klebsiella pneumonia* ATCC 70063. The results showed that in some cases the antibacterial activity of the complexes exceeded the one of sulfisoxazole used as a standard.

Keywords Crystal structure · Morpholine moiety · Antibacterial effects · Zinc(II) complex · Nickel(II) complex

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Introduction

The synthesis of heterocyclic systems containing nitrogen donor atoms has been attracting increasing interest over the past decade due to their utility in various applications, such as propellants, explosives, pyrotechnics, and especially chemotherapy [1, 2]. This investigation has been now extended to morpholine, a related six-membered heterocyclic ligand containing two donor sites (O and N atoms) [3]. Morpholine is a strong alkali, which can be considered as a kind of secondary aliphatic amine. However, the incorporation of nitrogen into the six-membered ring exposes the lone electron pair on nitrogen and makes the molecule a good nucleophile [4]. Morpholine and its derivatives are used extensively in many chemical reactions. The alkyl and aryl derivatives of morpholine occupy a pivotal place in chemical and pharmaceutical industries [5–8]. The *N*-alkyl and *N*-aryl derivatives of morpholine are important precursors in the

pharmaceutical preparations of analgesics, local anesthetics, antibiotics, antimycotics and also in the production of antiplaques. *N*-Methylmorpholine is used as a catalyst for the production of flexible and semiflexible polyurethane foam. *N*-Ethylmorpholine is used as a stabilizer for chlorinated hydrocarbons, extraction solvents, preparation of self-polishing waxes, oil emulsions, corrosion inhibitors, water reducible paints and pharmaceuticals. Aminopropyl morpholine is used as an intermediate for printing dyes, additives for fuels and lube oils and specialty surfactants [9–12]. Recently, synthesis and characterization of a new asymmetrical branched amine containing morpholine moiety was reported [13]. Herein, we report the synthesis and characterization of Zn(II) and Ni(II) complexes of 1,2-dimorpholinoethane. The X-ray crystal structure of these complexes is also reported. Also, the antibacterial activity of the ligand and its metal complexes is reported against the five Gram-positive bacteria: *Bacillus subtilis* ATCC 6633, *Staphylococcus aureus* ATCC 6538, *Bacillus cereus* NRRL-B-3711, *Enterococcus faecalis* ATCC 29212 and *Streptococcus pyogenes* and also against the three Gram-negative bacteria: *Eschericha coli* ATCC 11230, *Pseudomonas aeruginosa* ATCC 15442 and *Klebsiella pneumonia* ATCC 70063.

Experimental

Chemicals

Metal salts and other chemicals obtained from standard source suppliers (Merck, Aldrich) were of analytical grade and used without further purification. Solvents were distilled before use.

Physical measurements

All ^{1}H and ^{13}C NMR spectra were obtained on a BRUKER AC 400 MHz spectrometer using $CDCl_3$ or DMSO-d_6 as solvent and TMS as an internal standard. Chemical shifts (δ_H values in ^{1}HNMR, δ_C values in ^{13}CNMR) are quoted in units of parts per million (ppm) relative to an internal standard of Me_4Si. IR spectra were recorded as KBr pellets using a Perkin Elmer spectrum version 10.01.00 FT-IR spectrometer. Mass spectra were recorded by Agilent Technology (HP). Elemental analyses were performed on a Vario EL III CHNS system.

Synthesis

1,2-Dimorpholinoethane (DME)

The ligand was prepared according to a literature method [14].

General synthesis of the complexes

The zinc(II) and nickel(II) complexes were prepared by the branch tube method [15]: 1,2-dimorpholinoethane (DME) (1 mmol, 0.2 g) was placed in one arm of a branched tube and metal salts (1 mmol) in the other. Methanol was then carefully added to fill both arms, the tube sealed and the ligand-containing arm immersed in an oil bath at 60 °C, while the other was left at ambient temperature. After 15 days, the dark yellow and jade green crystals were collected in the cooler arm for zinc(II) and nickel(II) complexes, respectively. They were filtered off, washed with acetone and ether, and air dried.

Zn(II) complex

Yield: 0.248 g (74 %). Anal. calcd for $C_{10}H_{20}Cl_2N_2O_2Zn$: C 35.7, H 6.0, N 8.3; found: C 35.2, H 6.2, N 7.9, MS *m/z* (%): 334.8 ($C_{10}H_{20}Cl_2N_2O_2Zn$) and 263.3 ($C_{10}H_{20}N_2O_2$-$Zn)^{2+}$. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 3.3–3.4 (br, N–CH_2, 12H); 3.6–3.7 (t, O–CH_2, 8H); ^{13}C NMR (400 MHz, DMSO-d_6) δ: 65.8 C(c); 55.4 C(b); 54.6 C(a); IR (KBr), ν: 2954.31 and 2,854.07 (C–H); 1,441.44 (–CH_2–); 1,113.53 (C–N); 1,071.75 and 922.90 (C–O) cm^{-1}.

Ni(II) complex

Yield: 0.260 g (68 %). Anal. calcd for $C_{10}H_{20}N_4NiO_8$: C 31.4, H 5.3, N 14.6; found: C 31.7, H 5.2, N 14.9, MS *m/z* (%): 382.06 ($C_{10}H_{20}N_4O_8Ni$) and 258.09 ($C_{10}H_{20}N_2O_2$-$Ni)^{2+}$. IR (KBr), ν: 2,954.31 and 2,854.81 (C–H); 1,441.44 (–CH_2–); 1,113.53 (C–N); 1,071.75 and 922.90 (C–O) cm^{-1}.

X-ray crystal structural determination

Suitable single crystals of Zinc (**1**) and Nickel (**2**) complexes were mounted on a Gemini four-circle diffractometer of Agilent Technologies, equipped with a graphite collimated Mo Kα radiation ($\lambda = 0.7107$ Å) at $T = 120$ (10) K and area detector Atlas. Both compounds exhibited a twinning with partial overlaps of diffraction spots. During data processing, the information about overlaps was encoded in hklf5 format to be used later on in the structure refinement. The molecular structure plots were prepared using the ORTEP III [15]. The structure was solved by direct methods using SUPERFLIP program [16] and refined by full-matrix least-square technique on F^2, using JANA2006 [17] program with anisotropic displacement parameters for all non-hydrogen atoms. All hydrogen atoms were discernible in difference Fourier maps and could be refined to reasonable geometry. According to common practice, H atoms bonded to C were kept in ideal

Table 1 Crystallographic data and structure refinement summary for complexes **1** and **2**

Empirical formula	$C_{10}H_{20}Cl_2N_2O_2Zn$	$C_{10}H_{20}N_4NiO_8$
Formula weight	336.6	383
Temperature (K)	120	120
Wavelength (Å)	0.7107	0.7107
Crystal system	Triclinic	Triclinic
Space group	P-1	P-1
a (Å)	7.4695 (5)	7.3532 (3)
b (Å)	7.8404 (4)	7.8301 (4)
c (Å)	12.2339 (4)	13.4037 (6)
α (°)	104.800 (4)	99.382 (4)
β (°)	102.197 (4)	102.682 (3)
γ (°)	92.941 (5)	90.029 (3)
Volume (Å^3)	672.84 (6)	742.31 (6)
Z, D_{calc} (Mg/m^3)	2, 1.66	2, 1.713
μ (mm^{-1})	2.21	1.34
F(000)	348	400
Cryst size (mm^3)	0.20 × 0.20 × 0.15	0.67 × 0.51 × 0.46
Range for data collection (°)	2.95–29.5	3.2–29.3
h/*k*/*l*	−10 10/−10 10/−16,16	−9 10/−10 10/−18,18
Reflections collected/ unique	6,894/5,445 [*R*(int) = 0.033]	6,506/5,673 [*R*(int) = 0]
Absorption correction	Analytical	Analytical
Data/restraints/ parameters	6,894/0/155	6,506/0/209
goodness-of-fit on F^2	1.23	1.65
Final *R* indices [$I > 2$ s(*I*)]	R1 = 0.030, wR_2 = 0.081	R1 = 0.032, wR_2 = 0.090
R indices (all data)	R1 = 0.041, wR_2 = 0.077	R1 = 0.038, wR_2 = 0.087
Largest diff. peak, hole (eâ Å^{-3})	0.44 and −0.42	0.72 and −0.41

positions with C–H = 0.96 Å; the U_{iso} (H) was set to $1.2U_{eq}$(C, N). A summary of the crystallographic data and refinement parameters are given in Table 1, and the selected bond lengths for **1** and **2** are given in Table 2. Selected hydrogen bonds are presented in Table 3.

Antimicrobial activity

The in vitro antibacterial activity of the free ligand and their complexes were tested against the gram-positive bacteria; *B. subtilis* ATCC 6633, *B. cereus* NRRL-B-3711, *S. aureus* ATCC 6538, *E. faecalis* ATCC 29212, *S. pyogenes* (Group A streptococcus) and gram-negative bacteria, *E. coli* ATCC 11230, *P. aeruginosa* ATCC 15442, *K. pneumonia* ATCC 70063 by paper disc diffusion and microdilution broth methods.

Bacteria cultures were obtained from Hacettepe University Hospital, Microbiology Department. Bacterial strains were cultured overnight at 310 °K in Nutrient Broth. During the survey, these stock cultures were stored in the dark at 277 °K. The inocula of microorganisms were prepared from 12 h broth cultures and suspensions were adjusted to 0.5 McFarland standard turbidity.

Table 2 Selected bond lengths (Å) and angles (°) for complexes **1** and **2**

Complex 1			
Zn(1)–Cl(1)	2.2188 (6)	Zn(1)–N(6)	2.0939 (14)
Zn(1)–Cl(2)	2.2204 (6)	Zn(1)–N(9)	2.1095 (15)
Cl(1)–Zn(1)–Cl(2)	117.28 (2)	Cl(2)–Zn(1)–N(6)	109.21 (4)
Cl(1)–Zn(1)–N(6)	114.90 (5)	Cl(2)–Zn(1)–N(9)	114.28 (5)
Cl(1)–Zn(1)–N(9)	109.26 (4)	N(6)–Zn(1)–N(90)	88.49 (6)
Complex 2			
Ni1–O5	2.0525 (12)	Ni1–O8	2.0754 (12)
Ni1–O6	2.1299 (10)	Ni1–N2	2.1128 (11)
Ni1–O7	2.1232 (10)	Ni1–N4	2.1090 (12)
O5–Ni1–O6	97.35 (4)	O7–Ni1–N3	159.04 (4)
O5–Ni1–O7	61.96 (4)	O7–Ni1–O8	100.37 (4)
O5–Ni1–O8	155.13 (4)	O7–Ni1–N2	160.17 (4)
O5–Ni1–N2	98.61 (4)	O8–Ni1–N3	99.74 (4)
O5–Ni1–N3	102.27 (4)	O8–Ni1–N2	96.70 (4)
O6–Ni1–O7	82.97 (4)	N2–Ni1–N3	97.79 (4)
O6–Ni1–O8	61.39 (4)	O5–Ni1–N3	87.80 (5)
O6–Ni1–N2	96.57 (4)		

Table 3 Hydrogen bond lengths (Å) and bond angles (°) for complexes **1** and **2**[a]

D–H···A	D–H	H···A	D···A	D–H···A
Complex **1**				
C(4)–H(4A)···(O12)#1	0.9600	2.470	3.323 (2)	148
C(11)–H(11B)···(Cl2)	0.9600	2.80	3.629 (2)	144
C(4)–H(4B)···(Cl1)	0.9600	2.813	3.634 (2)	144
Complex **2**				
C(1)–(H1A)···(O7)	0.9600	2.39	3.211 (2)	143.00
C(5)–(H5A)···(O4) #2	0.9600	2.48	3.421 (2)	166.35
C(6)–(H6A)···(O8)	0.9600	2.46	3.014 (17)	116.22
C(9)–(H9A)···(O6)	0.9600	2.31	3.119 (18)	141.18
C(10)–(H10A)···(O3) #3	0.9600	2.38	3.308 (2)	162.22

[a] Symmetry transformations used to generate equivalent atoms: #1: $x + 1, y + 1, z$; #2: $-x + 1, -y, -z$; #3: $-x + 1, -y, -z + 1$

Disc diffusion method (in vitro)

The synthesized compounds were dissolved in dimethylsulfoxide (%20 DMSO) to a final concentration of 2.0 mg mL^{-1} and sterilized by filtration by 0.45 μm Millipore filters. Antimicrobial tests were then carried out by the disc diffusion method using 100 μL of suspension containing 10^8 CFU mL^{-1} bacteria spread on a nutrient agar (NA) medium. The discs (6 mm in diameter) were impregnated with 50 μL of each compound (100 μg/disc) at the concentration of 2.0 mg mL^{-1} and placed on the inoculated agar. DMSO impregnated discs were used as negative control. Sulfisoxazole (100 μg/disk) was used as positive reference standard to determine the sensitivity of one strain/isolate in each microbial species tested. The inoculated plates were incubated at 37 °C for 24 h for bacterial strains isolates. Antimicrobial activity in the disc diffusion assay was evaluated by measuring the zone of inhibition against the test organisms. Each assay in this experiment was repeated twice [18]. Percentage of inhibition was calculated by comparing the distance of the sample to the distance of the positive control using (sulfisoxazole) [19, 20].

Micro dilution assays

All tests were performed in a nutrient broth supplemented with DMSO to a final concentration of 20 % (v/v) to enhance their solubility. Test strains were suspended in the nutrient broth by adjusting to the 0.5 McFarland standards. The compounds to be tested were dissolved in DMSO to give the highest concentration (2,000 μg mL^{-1}), and serial dilutions thereafter in sterile 10 mL test tubes containing nutrient broth to give sample concentrations of the range 7.81–1,000 μg mL^{-1}. The minimum inhibitory concentration (MIC) values of compounds were determined using a modification of the micro-well dilution assay method. 100 μL from test compounds initially prepared at 1,000 μg mL^{-1} concentration was added into the first wells. Then, 100 μL from the serial dilutions was transferred into eight consecutive wells. The contents of the wells were mixed and the microplates were incubated at 37 °C for 24 h. The compounds were tested against each microorganism twice. The values obtained are average of the two results. The MIC values were determined from visual examinations as the lowest concentration of the extracts in the wells with no bacterial growth [21].

Results and discussion

Infrared spectra

The infrared spectra provide valuable information regarding the nature of functional group attached to the metal atom. The Infrared spectrum of the free ligand shows five bands in the regions 2,954, 2,854 (stretching C–H), 1,441 (–CH_2–), 1,071, 922 (C–O–C) cm^{-1}. Furthermore, the spectrum of the ligand shows a sharp band in the region 1,117 cm^{-1} assignable to C–N group, which is shifted to lower frequencies in the spectra of the complexes 1,113 cm^{-1} indicating the involvement of –C–N nitrogen in coordination to the metal ion.

^{1}H NMR and ^{13}C NMR spectra

The ^{1}H NMR spectrum of the 1,2-dimorpholinoethane showed the following signals: –N–CH_2 protons at 2.2–2.5 ppm (br, 12H), –O–CH_2 protons as triplet at 3.3–3.6 ppm (t, 8H). The ^{1}H NMR of the zinc complex also shows the following signals: –N–CH_2 protons at 3.3–3.4 ppm (br, 12H) and –O–CH_2 as triplet at 3.6–3.7 ppm (t, 8H). The –N–CH_2 protons signal in the spectrum of the Zn complex is shifted down field compared to the free ligand suggesting the bonding to the Zn atom through N attached with C–N group. There is no appreciable change in the –O–CH_2 signal of this complex. The ^{13}C NMR spectrum of 1,2-dimorpholinoethane shows three signals due to the presence of ten carbon atoms. The signal at 66.6 ppm is due to carbon atoms of C–O groups of the morpholine ring. The signal at 55.9 ppm is due to carbon atoms of C–N. The other signal of the ligand at 53.9 ppm is due to carbon atoms of CH_2 groups.

X-ray crystal structures

*Crystal structure of [Zn (DME) Cl_2] (**1**)*

The asymmetric unit (Fig. 1) of the title complex, $C_{10}H_{20}Cl_2N_2O_2Zn$, contains one zinc(II) cation, two chlorine anions and one 1,2-dimorpholinoethane (DME) ligand, all in general positions. Although Zn(II) ions prefer the six coordination form, four-coordinated tetrahedral complexes with ligands such as $C1^-$ are often obtained and this is also the case with the complex **1**. The Zn(II) cation is four-coordinated by two N atoms of the DME ligand and two Cl atoms, to form a slightly distorted tetrahedral (ZnN_2Cl_2) coordination geometry. The distortion is manifested by rather small N6–Zn–N9 ring angle (88.49 (6)°). The Zn–Cl distances are 2.2188 (6) and 2.2204 (6) Å, and Zn–N are 2.0939 (14) and 2.1095 (15) Å. The bond angles for Zn atom are in the range of 88.49 (6)°–117.28 (2)° (Table 2).

Although Zn(II) ions having preference for six coordination form, four-coordinated tetrahedral complexes with these ligands when $C1^-$ is used, in contrast to six-coordinated octahedral complexes when NO_3^- (2) is used as counter anions.

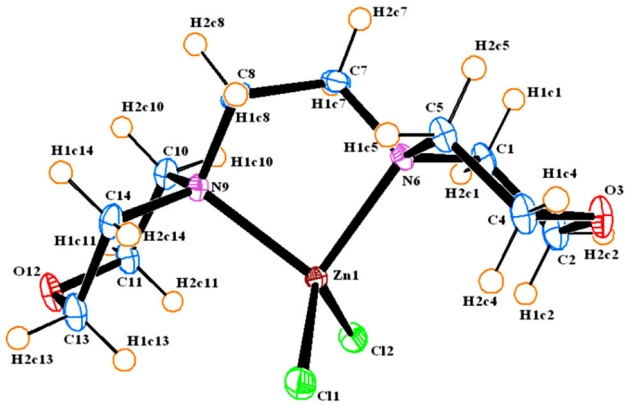

Fig. 1 The molecular structure of **1**, showing 40 % probability displacement ellipsoids and the atom-numbering

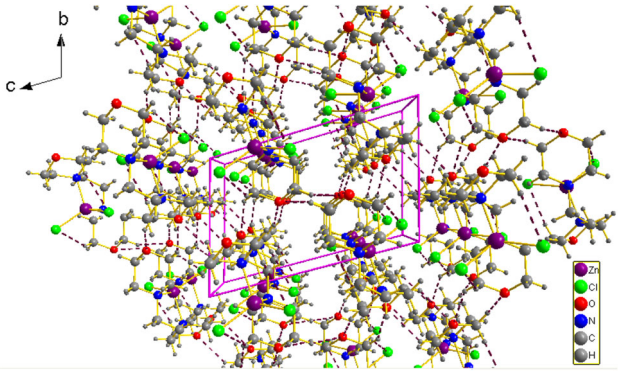

Fig. 2 Packing of the structure of **1** viewed along *a*-axis

Weak C–H···O hydrogen bonding is observed in the crystal structure. Moreover, the crystal structure is stabilized by intramolecular C–H···Cl interactions (Table 3; Fig. 2). In the complex, the morpholine rings adopt almost undistorted chair conformation: the torsion angles in the ring vary in a narrow range (57.33°–61.03°) and (57.61°–60.17°) for $N^{9}O^{12}C^{10-14}$ and $N^{6}O^{3}C^{1-5}$, respectively.

*Crystal structure of [Ni (DME) $(NO_3)_2$] (**2**)*

The molecular structure of the neutral nickel(II) complex is shown in Fig. 3. The asymmetric unit consists of one nickel(II) cation, two bidentate nitrate anions and one 1,2-dimorpholinoethane (DME) ligand, with all atoms in general positions. The coordination environment of the Ni(II) center has a distorted octahedral geometry, in which the nitrogen atoms from the DME ligand occupy two coordination sites and the oxygen atoms from two bidentate nitrate groups the four remaining sites [cisoid angles: 61.39 (4)–102.27 (4); transoid angles: 155.13 (4)–160.17 (4)] (Table 2).

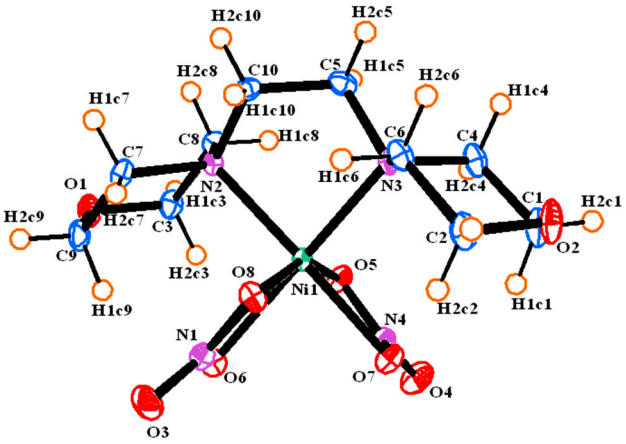

Fig. 3 The molecular structure of **2**, showing 50 % probability displacement ellipsoids and the atom-numbering

The Ni–O distance for the bidentate nitrate groups (av. 2.095 Å) is comparable with the calculated mean value [2.482 (144) Å] observed in Co complex [14], thus both oxygen atoms of nitrate ions are coordinated to the central Nickel ion. The Ni–N distances are in the normal range [from 2.109 (12) to 2.113 (11) Å)].

In the crystal structure, molecules are linked through intermolecular C–H···O hydrogen bonds to form a three-dimensional network (Table 3).

Antibacterial bioassay

The test compounds were screened in vitro for their antibacterial activity against five Gram-positive species (*B. subtilis* ATCC 6633, *B. cereus* NRRL-B-3711, *S. aureus* ATCC 6538, *E. faecalis* ATCC 29212, *S. pyogenes* (Group A streptococcus) and three Gram-negative species (*E. coli* ATCC 11230, *P. aeruginosa* ATCC 15442, *K. pneumonia* ATCC 70063) of bacterial strains by the disc diffusion and microdilution methods. The antibacterial activities obtained by disc diffusion are given in Table 4, while the results of the microdilution method are listed in Table 5.

The disc diffusion assay results demonstrate (Table 4) that 1,2-dimorpholinoethane ligand has exhibited the strong inhibition effect against most of the test bacteria. Both compounds have moderate activity against *B. subtilis* in the diameter zone of 10–14 mm whereas sulfisoxazole, the drug used as a standard, has exhibited no activity against the bacteria.

Percentage of inhibition for the compounds was expressed as excellent activity (120–200 % inhibition), good activity (90–100 % inhibition), moderate activity (75–85 % inhibition), significant activity (50–60 % inhibition), negligible activity (20–30 % inhibition) and no activity [22, 23]. At this scale, both tested compounds have good activity against *P. aeruginosa*. With *E. faecalis*, the

Table 4 Measured inhibition zone diameter (mm) of the compounds and antibiotics by disc diffusion method

Bacteria strains	Diameter inhibition zone* (mm 100 μg/disk)			
	1,2-Dimorpholinoethane	Ni complex	Zn complex	Sulfisoxazole
Gram-negative				
Eschericha coli ATCC 11230	10	10	10	14
Pseudomonas aeruginosa ATCC 15442	9	10	10	9
Klebsiella pneumonia ATCC 70063	13	9	12	21
Gram-positive				
Bacillus subtilis ATCC 6633	12	12	14	–
Bacillus cereus NRRL-B-3711	10	9	11	11
Staphylococcus aureus ATCC 6538	10	10	12	15
Enterococcus faecalis ATCC 29212	13	10	15	11
Streptococcus pyogenes	10	9	13	13

<10: weak; >10 moderate; >16: significant

* Average values

Table 5 The MICs of antibacterial activity of the compounds

Bacteria strains	MIC* μg mL^{-1} (mM)			
	1,2-Dimorpholinoethane	Ni complex	Zn complex	Sulfisoxazole
Gram-negative				
Eschericha coli ATCC 11230	500 (2.41)	250 (0.64)	250 (0.74)	23.4 (0.088)
Pseudomonas aeruginosa ATCC 15442	500 (2.41)	250 (0.64)	250 (0.74)	375 (1.40)
Klebsiella pneumonia ATCC 70063	125 (0.60)	500 (1.28)	250 (0.74)	23.4 (0.088)
Gram-positive				
Bacillus subtilis ATCC 6633	250 (1.21)	250 (0.64)	125 (0.37)	–
Bacillus cereus NRRL-B-3711	250 (1.21)	250 (0.64)	250 (0.74)	375 (0.088)
Staphylococcus aureus ATCC 6538	250 (1.21)	250 (0.64)	125 (0.37)	93.75 (0.35)
Enterococcus faecalis ATCC 29212	125 (0.60)	250 (0.64)	125 (0.37)	93.75 (0.35)
Streptococcus pyogenes	250 (1.21)	250 (0.64)	125 (0.37)	11.7 (0.044)

* Average values

complex **1** shows an excellent activity, whereas rests of the complex **2** have good activity or moderate activity against *E. faecalis* and *B. cereus*.

According to the MIC's results shown in Table 5, both compounds possess an activity against the tested bacteria at the concentrations of 125–500 μg mL^{-1}. Both compounds show good activity against *B. subtilis* at the concentrations 125–250 μg mL^{-1}, whereas sulfisoxazole has no activity. Depending on the units of concentration, activity order of compounds would be different. When we use mM units, the complex **1** has higher activity against most of the test bacteria comparing with complex **2**. The Zn complex also shows activity against *P. aeruginosa* at a concentration of 0.74 mM, while sulfisoxazole is inactive.

Conclusion

The work described in this paper involved the synthesis and spectroscopic characterization of nickel and zinc complexes with symmetrical ligand (DME), containing morpholine moiety. The ligand and related complexes were characterized using different physiochemical techniques. Molecular structures for the complexes [Zn (DME) Cl_2] and [Ni (DME) $(NO_3)_2$] have been determined by single crystal X-ray analysis. The complexes are neutral with a distorted tetrahedral and octahedral geometry for complexes **1** and **2**, respectively. They exhibited antibacterial activity against five Gram-positive bacteria: *B. subtilis* ATCC 6633, *S. aureus* ATCC 6538, *B. cereus* NRRL-B-3711, *E. faecalis* ATCC 29212 and *S. pyogenes* and also against three Gram-negative bacteria: *E. coli* ATCC 11230, *P. aeruginosa* ATCC 15442 and *K. pneumonia* ATCC 70063. In some cases, the antibacterial activity of complexes outreach the one of sulfisoxazole used as a standard.

Supplementary data

CCDC 950105 and 950183 contains the supplementary crystallographic data for [Zn (DME) Cl_2] and [Ni (DME)

$(NO_3)_2$]. These data can be obtained free of charge via http://www.ccdc.cam.ac.uk/conts/retrieving.html, or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: (+44) 1223-336-033; or e-mail: deposit@ccdc.cam.ac.uk.

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