ISSN 1070-3284, Russian Journal of Coordination Chemistry, 2016, Vol. 42, No. 2, pp. 137–142. © Pleiades Publishing, Ltd., 2016.

Dioxomolybdenum(VI) Complexes Derived from Tridentate Hydrazone Ligands: Synthesis, Characterization, Crystal Structures, and Antibacterial Activity[1]

L. Xue, D. Deng, Y. Xu, and Q. Wang*

Modern Medical Research Center, Third Affiliated Hospital of Soochow University, Changzhou, 213003 P.R. China

**e-mail: wangqiangszu@126.com*

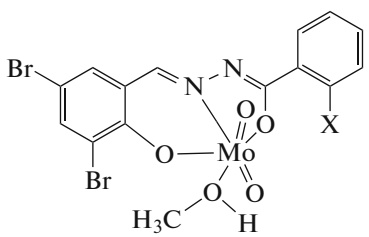
Received May 5, 2015

Abstract—A pair of structurally similar dioxomolybdenum(VI) complexes with general formula $[MoO_2(L)(MeOH)]$ (L = L^1 = *N*′-(3,5-dibromo-2-hydroxybenzylidene)-2-hydroxybenzohydrazide for **I**, L = L^2 = *N*′-(3,5-dibromo-2-hydroxybenzylidene)-2-methylbenzohydrazide for **II**), have been prepared and characterized by elemental analysis, IR spectra, and single crystal X-ray determination (CIF files CCDC nos. 917823 (**I**) and 917824 (**II**)). The hydrazone ligands coordinate to the Mo atoms through phenolate oxygen, imine nitrogen, and enolic oxygen atoms. The Mo atom in each complex is six-coordinated in an octahedral geometry. The crystals of the complexes are stabilized by hydrogen bonds. The complexes and the ligands were assayed for antibacterial activities against three Gram-positive bacterial strains (*B. subtilis*, *S. aureus*, and *S. faecalis*) and three Gram-negative bacterial strains (*E. coli*, *P. aeruginosa*, and *E. cloacae*) by MTT method. As a result, the complexes showed effective antimicrobial activity against the microorganisms tested.

DOI: 10.1134/S1070328416020093

INTRODUCTION

In the last few years, molybdenum complexes with different kinds of ligands have been widely investigated for their catalytic properties on a variety of organic substrates [1–4], particularly for sulfoxidation and epoxidation of olefins [5–8]. Hydrazone ligands, bearing –CH=N–NH–C(O)– groups, have been attracted considerable attention in coordination chemistry and bioinorganic chemistry [9, 10]. Dioxomolybdenum complexes derived from hydrazone ligands have been proved to possess versatile catalytic properties [11, 12]. However, study on the antibacterial activity of such complexes is insignificantly. In the present work, a pair of new dioxomolybdenum(VI) complexes with general formula $[MoO_2(L)(MeOH)]$ (**I**) and (**II**), where L = L^1 = *N*′-(3,5-dibromo-2-hydroxybenzylidene)-2-hydroxybenzohydrazide, L = L^2 = *N*′-(3,5-dibromo-2-hydroxybenzylidene)-2-methylbenzohydrazide, are reported.



X = OH (**I**) and CH_3 (**II**)

[1] The article is published in the original.

EXPERIMENTAL

Materials and methods. 3,5-Dibromo-2-hydroxybenzaldehyde, 2-hydroxybenzohydrazide, and 2-methylbenzohydrazide were purchased from Sigma-Aldrich. $MoO_2(Acac)_2$ and other chemicals (AR grade) were commercial available and used as received. C, H, and N elemental analyses were determined on a Perkin-Elmer 2400 II Elemental Analyser. FT-IR spectra were recorded in the range 2004000 cm^{-1} on a Perkin-Elmer Spectrum RX I FT-IR spectrophotometer with KBr pressed pellets.

Synthesis of complex $[MoO_2(L^1)(MeOH)]$ (I). $MoO_2(Acac)_2$ (65.2 mg, 0.2 mmol) dissolved in 10 mL methanol was added dropwise to a methanol solution of L^1 (82.8 mg, 0.2 mmol) with continuous stirring for 30 min to give a yellow solution. Evaporation of the solution at room temperature yielded orange block-shaped single crystals after a few days. The crystals were isolated by filtration and dried in air. The yield was 63%.

For $C_{15}H_{12}N_2O_6Br_2Mo$

anal. calcd., %:	C, 31.5;	H, 2.1;	N, 4.9.
Found, %:	C, 31.3;	H, 2.2;	N, 5.0.

Synthesis of complex $[MoO_2(L^2)(MeOH)]$ (II) was analogous to procedure for **I** but with L^1 replaced by L^2

Table 1. Crystallographic data and structure refinement summary for **I** and **II**

Parameter	Value	
	I	**II**
Fw	572.0	570.0
Crystal shape/color	Block/orange	Block/orange
Crystal size, mm	0.23 × 0.21 × 0.20	0.23 × 0.21 × 0.20
Crystal system	Monoclinic	Monoclinic
Space group	$P2_1/n$	$P2_1/n$
a, Å	13.2626(7)	7.9866(7)
b, Å	7.8146(4)	14.0221(12)
c, Å	17.9581(9)	16.5317(14)
β, deg	102.256(2)	92.308(3)
V, Å^3	1818.8(2)	1849.9(3)
Z	4	4
T, K	298(2)	298(2)
μ, cm^{-1}	5.149	5.059
T_{min}/T_{max}	0.3838/0.4257	0.3891/0.4311
Measured reflections	18876	17683
Unique reflections	3375	4017
Observed reflections ($I \geqslant 2\sigma(I)$)	2890	2977
Parameters/restraints	239/1	240/1
GOOF on F^2	1.040	1.176
R_1, wR_2 ($I \geqslant 2\sigma(I)$)*	0.0283, 0.0616	0.0751, 0.1706
R_1, wR_2 (all data)*	0.0380, 0.0662	0.1063, 0.1820

* $R_1 = \Sigma||F_o| - |F_c||/\Sigma|F_o|$, $wR_2 = [\Sigma w(F_o^2 - F_c^2)^2/\Sigma w(F_o^2)^2]^{1/2}$.

(82.4 mg, 0.2 mmol). The yield the range block-shaped single crystals of **II** was 55%.

For $C_{16}H_{14}N_2O_5Br_2Mo$

anal. calcd., %:	C, 33.7;	H, 2.5;	N, 4.9.
Found, %:	C, 33.6;	H, 2.5;	N, 4.8.

X-ray structure determination. A diffraction quality single crystal of the complex was mounted on a Bruker Apex II CCD area diffractometer equipped with a graphite monochromator and MoK_α radiation (λ = 0.71073 Å). Data collection was carried out using the Bruker APEX2 software. Multi-scan absorption correction was applied using SADABS [13]. The structure of the complex was solved by direct method with SHELXS and refined by full-matrix least-squares based on F^2 with SHELXL [14]. All non-hydrogen atoms were refined anisotropically. The methanol hydrogen atoms were located from difference Fourier maps and refined isotropically, with O–H distances restrained to 0.85(1) Å. The remaining hydrogen atoms were included in the final refinement of the calculated positions riding on their parent atoms. Further crystallographic analysis and figure production were carried out using PLATON99 [15] and ORTEP [16] programs. Details of the data collection parameters and crystallographic information for the complex are given in Table 1. Coordinate bond lengths and angles are listed in Table 2.

Supplementary material has been deposited with the Cambridge Crystallographic Data Centre (CCDC nos. 917823 (**I**) and 917824 (**II**); deposit@ccdc.cam.ac.uk or http://www.ccdc.cam.ac.uk).

Antibacterial activity. Antibacterial activity of the complex was tested against *B. subtilis*, *S. aureus*, *S. faecalis*, *P. aeruginosa*, *E. coli*, and *E. cloacae* using MTT medium. The minimum inhibitory concentrations (MICs) of the complex were determined by a colorimetric method using MTT dye [17]. A stock solution of the complex (50 μg mL^{-1}) in DMSO was prepared and quantities of the complex were incorporated in specified quantity of sterilized liquid medium. A specified quantity of the medium containing the complex was poured into microtitration plates. Suspension of the microorganism was prepared to contain approxi-

Table 2. Selected bond lengths (Å) and bond angles (deg) for complexes **I**, **II**

Bond	*d*, Å	Bond	*d*, Å
		I	
Mo(1)–O(1)	1.929(2)	Mo(1)–O(2)	2.007(2)
Mo(1)–O(3)	2.335(3)	Mo(1)–O(4)	1.689(3)
Mo(1)–O(5)	1.693(2)	Mo(1)–N(1)	2.262(3)
		II	
Mo(1)–O(1)	1.945(6)	Mo(1)–O(2)	2.019(7)
Mo(1)–O(3)	2.320(7)	Mo(1)–O(4)	1.677(7)
Mo(1)–O(5)	1.700(7)	Mo(1)–N(1)	2.238(7)
Angle	ω, deg	Angle	ω, deg
		I	
O(4)Mo(1)O(5)	105.61(12)	O(4)Mo(1)O(1)	99.30(13)
O(5)Mo(1)O(1)	103.03(11)	O(4)Mo(1)O(2)	96.83(13)
O(5)Mo(1)O(2)	97.75(11)	O(1)Mo(1)O(2)	149.08(10)
O(4)Mo(1)N(1)	93.95(11)	O(5)Mo(1)N(1)	158.82(11)
O(1)Mo(1)N(1)	81.25(9)	O(2)Mo(1)N(1)	71.44(9)
O(4)Mo(1)O(3)	170.78(11)	O(5)Mo(1)O(3)	83.30(11)
O(1)Mo(1)O(3)	80.62(11)	O(2)Mo(1)O(3)	79.33(11)
N(1)Mo(1)O(3)	76.90(9)		
		II	
O(4)Mo(1)O(5)	105.8(3)	O(4)Mo(1)O(1)	97.4(3)
O(5)Mo(1)O(1)	103.8(3)	O(4)Mo(1)O(2)	96.6(3)
O(5)Mo(1)O(2)	97.9(3)	O(1)Mo(1)O(2)	149.8(3)
O(4)Mo(1)N(1)	95.7(3)	O(5)Mo(1)N(1)	157.0(3)
O(1)Mo(1)N(1)	80.8(3)	O(2)Mo(1)N(1)	71.2(3)
O(4)Mo(1)O(3)	171.3(3)	O(5)Mo(1)O(3)	82.4(3)
O(1)Mo(1)O(3)	83.2(3)	O(2)Mo(1)O(3)	79.1(3)
N(1)Mo(1)O(3)	75.8(3)		

mately 10^5 cfu mL^{-1} and applied to microtitration plates with serially diluted complexes in DMSO to be tested, and incubated at 37°C for 24 h for bacteria. After the MICs were visually determined on each microtitration plates, 50 μL of phosphate buffered saline (PBS 0.01 mol L^{-1}, pH 7.4 and 2.9 g $Na_2HPO_4 \cdot 12H_2O$, 0.2 g KH_2PO_4, 8.0 g NaCl, 0.2 g KCl, 1000 mL distilled water) containing 2 mg mL^{-1} of MTT was added to each well. Incubation was continued at room temperature for 4–5 h. The content of each well was removed and 100 μL of isopropanol containing 5% 1 mol L^{-1} HCl was added to extract the dye. After 12 h of incubation at room temperature, the optical density (OD) was measured with a microplate reader at 570 nm.

RESULTS AND DISCUSSION

The dioxomolybdenum(VI) complexes were readily synthesized by reaction of $MoO_2(Acac)_2$ with hydrazone ligands in methanol. The ligands adopt enolic tautomeric forms on complexation. Orange single crystals of the complexes were obtained by recrystallization of the complexes in methanol, which are soluble in polar organic solvents such as DMF, DMSO, acetonitrile, methanol, and ethanol, but hardly soluble in water. During the search of literature, it can be observed that most of the oxovanadium complexes contain methanol molecules as coligands, instead of ethanol molecules [12, 18–20].

The IR spectra of the free hydrazone ligands exhibit two absorption bands in the regions 3200–3270 and 1650–1670 cm^{-1} due to the ν(N–H) and ν(C=O) stretches. The absence of these bands in the spectra of the dioxomolybdenum(VI) complexes is consistent with the enolisation of the amide functionality and subsequent proton replacement by the Mo atoms. The strong bands at about 1615 cm^{-1} in both complexes are assigned to the conjugate C=N–N=C moieties [21]. The intense absorption bands in the

Table 3. MICs (μg mL^{-1}) of the complexes and related material

Tested material	Gram positive			Gram negative		
	B. subtilis	*S. aureus*	*S. faecalis*	*P. aeruginosa*	*E. coli*	*E. cloacae*
I	0.78	3.12	12.5	6.25	0.39	
II	0.78	3.12	25	6.25	0.39	
H_2L^1	6.25	6.25			12.5	
H_2L^2	6.25	12.5			25	
Penicillin	1.56	1.56	1.56	6.25	6.25	3.12
Kanamycin	0.39	1.56	3.12	3.12	3.12	1.56

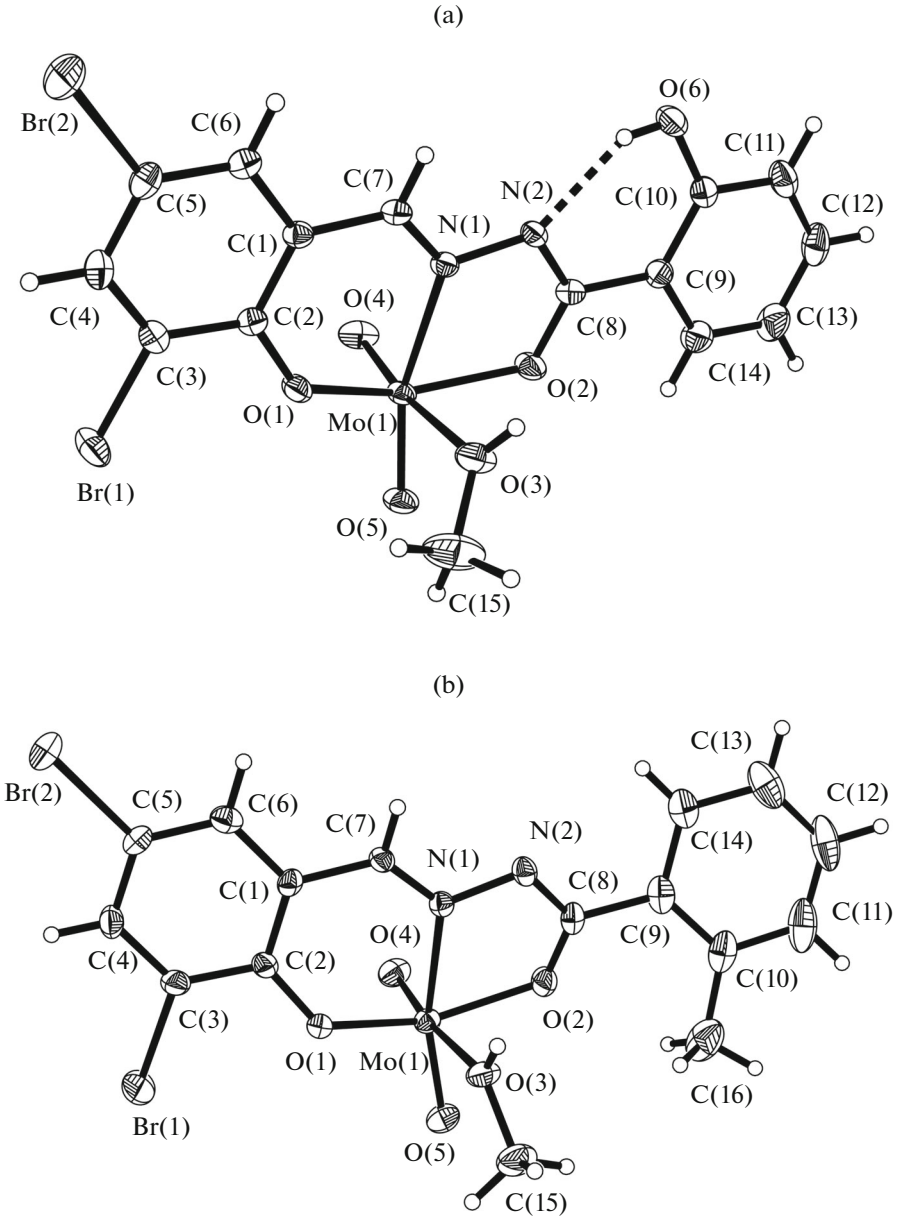


Fig. 1. An ORTEP plots of complexes **I** (a) and **II** (b). Ellipsoids are drawn at 30% probability level.

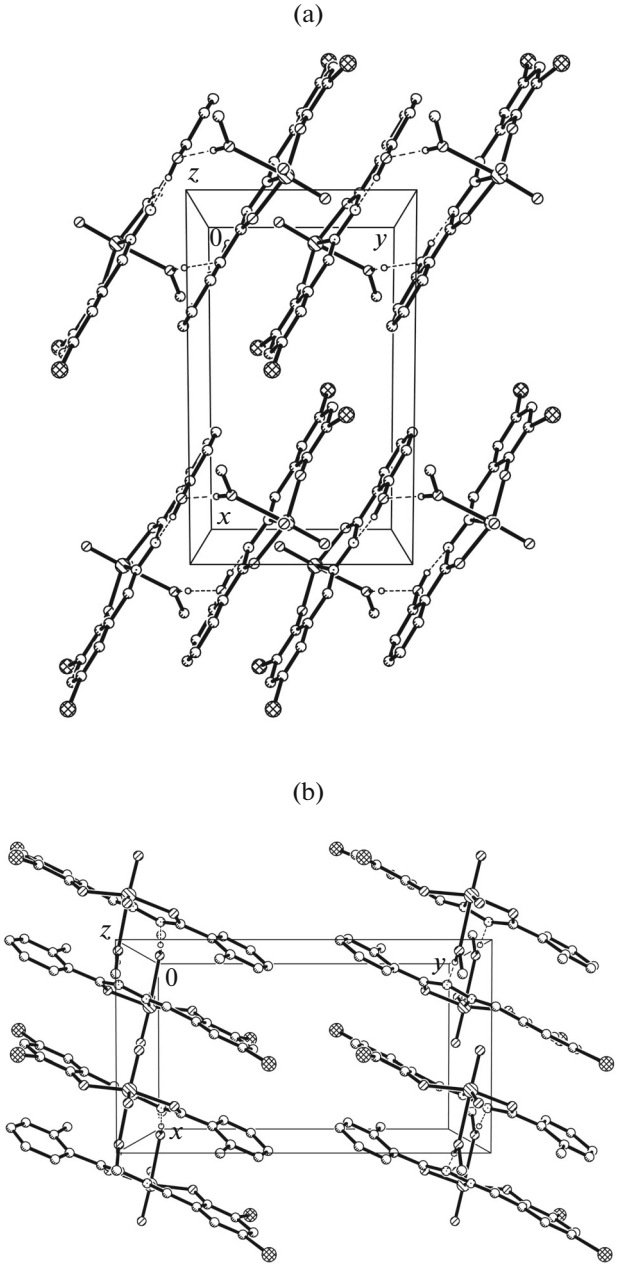


Fig. 2. Molecular packing diagrams of complexes **I** (a) and **II** (b), viewed down the *z* axis. Hydrogen atoms have been omitted for clarity.

spectra of both complexes corresponding to the ν(Mo=O) are observed at about 920 cm^{-1} for both complexes [22].

The molecular structures including the atomic numbering scheme of the complexes **I** and **II** are shown in Fig. 1. Both complexes are mononuclear dioxomolybdenum compounds. The tridentate hydrazone ligands coordinate to the Mo atoms through the phenolate O, imino N and enolic O atoms. The dihedral angles between the two benzene rings of the hydrazone ligands are 5.3(3)° for **I** and 9.4(3)° for **II**. The Mo atom in each complex is in an octahedral coordination, with the three donor atoms of the hydrazone ligand, and one oxo O atom defining the equatorial plane, and with another oxo O and one methanol O atom occupying the two axial positions. The mean deviations of the four equatorial donor atoms from the least-squares planes are 0.011(3) Å for **I** and 0.046(3) Å for **II**. The displacement of the Mo atoms toward the axial oxo groups from the planes are 0.320(2) Å for **I** and 0.316(2) Å for **II**. The coordinate bond lengths and angles in the complexes are comparable to each other, and also comparable to those observed in other similar dioxomolybdenum(VI) complexes [12, 17–19]. The *cis* bond angles are in the range 71.4(1)°–105.6(1)° for **I** and 71.2(3)°–105.8(3)° for **II**, and the *trans* bond angles are in the range 149.1(1)°–170.8(1)° for **I** and 149.8(3)°–171.3(3)° for **II**. The shorter Mo(1)–O(4) and Mo(1)–O(5) bonds in both complexes than other coordinate bonds, indicating they are typical double bonds. As commonly observed in analogous species, the elongated Mo(1)–O(3) bonds *trans* to the oxo groups, O(4), in the complexes indicate weak coordination of the methanol ligands at the axial positions.

In the crystal structures of complexes **I** and **II**, adjacent two molecules are linked through intermolecular hydrogen bonds (O(3)–H(3)···O(6)^{i} for **I**: O(3)–H(3) 0.85(1), H(3)···O(6)^{i} 1.94(1), O(3)···O(6)^{i} 2.784(4) Å, O(3)–H(3)···O(6)^{i} 179(5)°; O(3)–H(3)···N(2)^{ii} for **II**: O(3)–H(3) 0.85(1), H(3)···N2)^{ii} 1.94(2), O(3)···N(2)^{ii} 2.784(11) Å, O(3)–H(3)···N(2)^{ii} 176(8)°. Symmetry codes: ^{i} $1-x$, $1-y$, $-z$; ^{ii} $-x$, $-y$, $1-z$), forming dimers (Fig. 2).

The complexes and the hydrazone ligands were screened for antibacterial activities against three Gram-positive bacterial strains (*B. subtilis*, *S. aureus*, and *S. faecalis*) and three Gram-negative bacterial strains (*E. coli*, *P. aeruginosa*, and *E. cloacae*) by MTT method. The MICs of the complexes against the bacteria are presented in Table 3. Penicillin and kanamycin were tested as reference compounds. The antibacterial activities of the complexes are in general more effective than the hydrazone ligands themselves. The free hydrazones are inactive against the Gram-positive bacterial strain *S. faecalis* and the Gram-negative bacterial strain *P. aeruginosa*, and showed medium activity against the Gram-positive bacterial strains *B. subtilis* and *S. aureus*, and the Gram-negative bacterial strains *E. coli*. The complexes exhibited significant activities against *B. subtilis*, *S. aureus* and *E. coli*, and medium activity against *S. faecalis* and *P. aeruginosa*. As for the Gram-negative bacterial strain *E. cloacae*, both the hydrazone ligands and the complexes have no activity.

ACKNOWLEDGMENTS

Financial support from the Third Affiliated Hospital of Soochow University is gratefully acknowledged.

REFERENCES

1. Bagherzadeh, M., Amini, M., Ellern, A., et al., *Inorg. Chem. Commun.*, 2012, vol. 15, no. 1, p. 52.
2. Calhorda, M.J. and Costa, P.J., *Curr. Org. Chem.*, 2012, vol. 16, no. 1, p. 65.
3. Maurya, M.R., *Curr. Org. Chem.*, 2012, vol. 16, no. 1, p. 73.
4. Krackl, S., Company, A., Enthaler, S., et al., *ChemCatChem*, 2011, vol. 3, no. 7, p. 1186.
5. Rayati, S., Rafiee, N., and Wojtczak, A., *Inorg. Chim. Acta*, 2012, vol. 386, no. 1, p. 27.
6. Amarante, T.R., Neves, P., Tome, C., et al., *Inorg. Chem.*, 2012, vol. 51, no. 6, p. 3666.
7. Gamelas, C.A., Gomes, A.C., Bruno, S.M., et al., *Dalton Trans.*, 2012, vol. 41, no. 12, p. 3474.
8. Coelho, A.C., Nolasco, M., Balula, S.S., et al., *Inorg. Chem.*, 2011, vol. 50, no. 2, p. 525.
9. Raja, D.S., Bhuvanesh, N.S.P., and Natarajan, K., *J. Biol. Inorg. Chem.*, 2012, vol. 17, no. 3, p. 223.
10. Jin, N.-Y., *J. Coord. Chem.*, 2012, vol. 65, no. 22, p. 4013.
11. Bagherzadeh, M., Amini, M., Parastar, H., et al., *Inorg. Chem. Commun.*, 2012, vol. 20, no. 1, p. 86.
12. Rao, S.N., Munshi, K.N., Rao, N.N., et al., *Polyhedron*, 1999, vol. 18, no. 19, p. 2491.
13. Sheldrick, G.M., *SADABS, Programs for Area Detector Adsorption Correction*, Göttingen: Univ. of Göttingen, 1996.
14. Sheldrick, G.M., *SHELXTL, Version 5.1, Program for the Solution and Refinement of Crystal Structures*, Madison: Bruker AXS Inc., 1999.
15. Spek, A.L., *PLATON, Molecular Geometry Program*, The Netherlands: Univ. of Utrecht, 1999.
16. Farrugia, L.J., *J. Appl. Crystallogr.*, 1997, vol. 30, p. 565.
17. Meletiadis, J., Meis, J.F., Mouton, J.W., et al., *J. Clin. Microbiol.*, 2000, vol. 38, no. 8, p. 2949.
18. Zhai, Y.-L., Xu, X.-X., and Wang, X., *Polyhedron*, 1992, vol. 11, no. 4, p. 415.
19. Bansse, W., Ludwig, E., Schilde, U., et al., *Z. Anorg. Allg. Chem.*, 1995, vol. 621, p. 1275.
20. Mancka, M. and Plass, W., *Inorg. Chem. Commun.*, 2007, vol. 10, no. 6, p. 677.
21. Ngan, N.K., Lo, K.M., and Wong, C.S.R., *Polyhedron*, 2011, vol. 30, no. 17, p. 2922.
22. Dinda, R., Sengupta, P., Ghosh, S., et al., *Dalton Trans.*, 2002, no. 15, p. 4434.