



Trade Science Inc.

ISSN : 0974 - 746X

Volume 7 Issue 2

Inorganic CHEMISTRY

An Indian Journal

Full Paper

ICAIJ, 7(2), 2012 [82-93]

Synthesis, characterization, semi-empirical study and alkaline phosphatase activity of vanadyl(IV) complexes with N/O- and O-donor ligands

Khurram Shahzad Munawar¹, Saqib Ali*¹, Allah Nawaz Khan², Saira Shahzadi³,
Saroj K.Sharma⁴, Kushal Qanungo⁴

¹Department of Chemistry, Quaid-i-Azam University, Islamabad - 45320, (PAKISTAN)

²Department of Biochemistry, Capital Hospital, CDA, Islamabad, (PAKISTAN)

³Department of Chemistry, GC University, Faisalabad, (PAKISTAN)

⁴Department of App. Sci. and Hum., Faculty of Engg. and Tech., Mody Institute of Technology and Science (Deemed University), Lakshmanmangarh - 332 311, Dist Sikar, Raj., (INDIA)

E-mail: drsa54@yahoo.com; sairashahzadi@hotmail.com

Received: 6th March, 2012 ; Accepted: 6th April, 2012

ABSTRACT

Various N/O- and O-donor ligands and their vanadyl(IV) complexes have been synthesized and characterized by different techniques such as FTIR, elemental analysis, thermogravimetry and conductivity. The IR data shows the bidentate nature of the ligands and reveals hexa-coordinated geometry in the solid state which is also confirmed by semi-empirical study. Conductance measurements reveal the non-electrolytic nature of the complexes. These complexes have been checked for their alkaline phosphatase activity in the presence and absence of inhibitor which shows that by the addition of inhibitor the activity of enzyme decreases and at higher concentration it is completely inhibited. © 2012 Trade Science Inc. - INDIA

KEYWORDS

Vanadyl(IV) complexes;
Spectroscopy;
Conductance;
Semi-empirical study;
Alkaline phosphatase
activity.

INTRODUCTION

Vanadium compounds show interesting biochemical and pharmacological properties^[1]. Intensive studies carried out over the last two decades^[2] showed that vanadium is one of the most important supplements for oral diabetes therapy^[3]. Inorganic vanadium salts are poorly absorbed from the digestive system, thus high oral doses are required. Therefore, various vanadium ions-organic ligand complexes were tested in order to obtain more potent medicines than inorganic vanadium salts^[4]. Enzymes containing vanadium as an essential element were isolated in the 1980's. These enzymes are able to exercise the activities of nitrogenase and

bromoperoxidase¹. Presently, numerous papers deal with the vanadium biochemistry^[1,5]. Several vanadium compounds have recently been investigated in animal model systems as treatment for diabetes^[6,7] and studies in clinical trials in human beings with organic transition metal complex have been developed^[8].

Tetradentate schiff base complexes of oxovanadium(IV), VO²⁺, have been the subjects of various studies^[9-15]. The use of chiral oxovanadium(IV) complexes in the preparation of chiral sulfoxide for the pharmaceutical industry has been widely studied^[9,10]. Other area of great interest is the role of the vanadium species in oxygen atom or electron transfer reactions^[5].

Vanadium(IV) complexes with Schiff bases encap-

sulated in the Y zeolite can act as peroxidase mimics^[16]. The ship-in-a-bottle approach presents many advantages: (i) zeolites have well-organized nanoporous and nanochannels, which readily serve as supporting hosts for various molecules; (ii) the zeolite replaces protein portion of natural enzymes and provides a controlled steric environment for the metal complex, serving as a model for the active site of cytochrome P-450^[17-20]. There is a great deal of interest of vanadium complexes with the ligands of mixed donor atoms such as oxygen, nitrogen and sulphur because these ligands incorporate by its donor atoms both medium crystal field strength (nitrogen donors) and low crystal field strength (sulphur ligands) to generate complexes of unusual stereochemistry^[21]. In most cases the active site contains either of these two moieties, VO²⁺ and VO³⁺, coordinated by oxygen and nitrogen atoms. This strong affinity, is probably due to their hard acidic nature and selective stabilization of these two moieties, depends upon basicity of donor atoms. Sulphur atoms show less coordination^[22].

In order to extend the research and to fully understand the exact role of vanadium complexes in biological system great efforts have been made to prepare and investigate oxovanadium(IV) complexes derived from various ligands^[23,24].

In continuation to that we are reporting here synthesis of oxovanadium complexes with N/O and O-donor ligands and their characterization by different techniques such as FTIR, elemental analysis, thermogravimetry, semiempirical study and conductometry. These complexes have also been checked for their alkaline phosphatase activity.

EXPERIMENTAL

Materials and methods

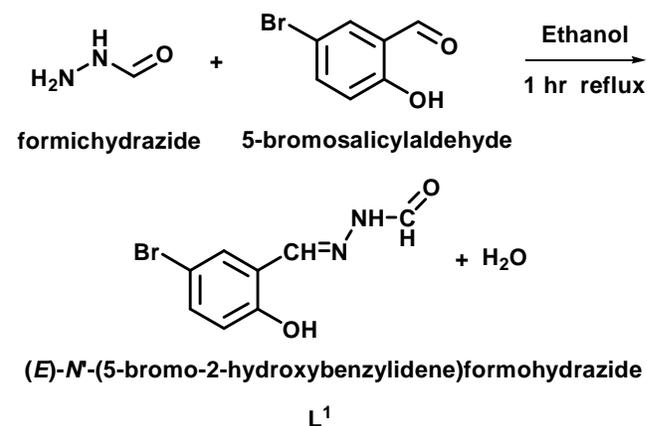
The chemicals were of analytical grade and were used without further purification. VOSO₄·3H₂O was procured from Aldrich. Organic solvents were dried before use according to the standard procedure^[25].

Melting points were obtained using an Electrothermal melting point apparatus model MP-D Mitamura Riken Kogyo (Japan) and are uncorrected. Infrared spectra in the region of 4000-400 cm⁻¹ were obtained as KBr discs with a Bio-Red Merlin FTS 3000 MX

(USA). Conductance measurements were made using EC meter model Cyber Scan 500. Thermogravimetric analysis was carried out on a Perkin Elmer Thermogravimetric Analyzer TGA7. Elemental Analysis was carried out by CHNS-932 Elemental Analyzer Leco Corporation USA. The molecules were modeled by MOPAC 2007^[26] program in gas phase using PM6 method^[27]. Selected parts of the complexes not containing the metal ion were preoptimised using molecular mechanics methods. Several cycles of energy minimization had to be carried for each of the molecules. In ligands containing NHCO group molecular mechanics correction was applied. The Root Mean Square Gradient for molecules was all less than one. Self Consistent Field was achieved in each case.

Synthesis of 5-bromo-2-hydroxybenzylideneformohydrazide L¹

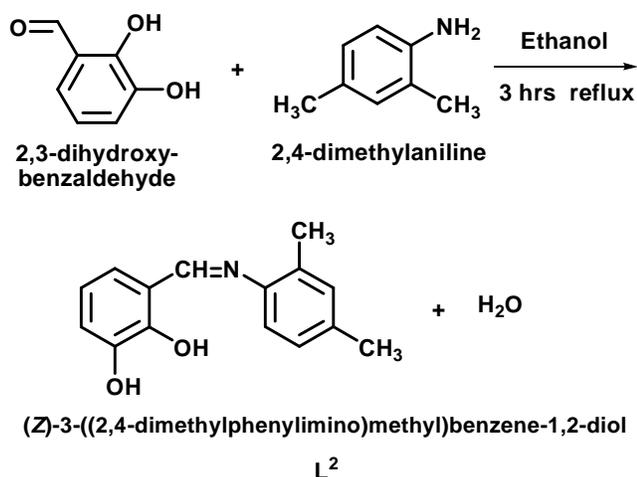
Formichydrazide (1 mmol) and 5-bromosalicylaldehyde (1 mmol) were dissolved separately in 50 ml of ethanol. Both solution were mixed and refluxed for 1 hr with continuous stirring in round bottom flask. Solvent was evaporated by using rotary evaporator under reduced pressure. The solid product obtained was recrystallized in chloroform:*n*-hexane (1:1).



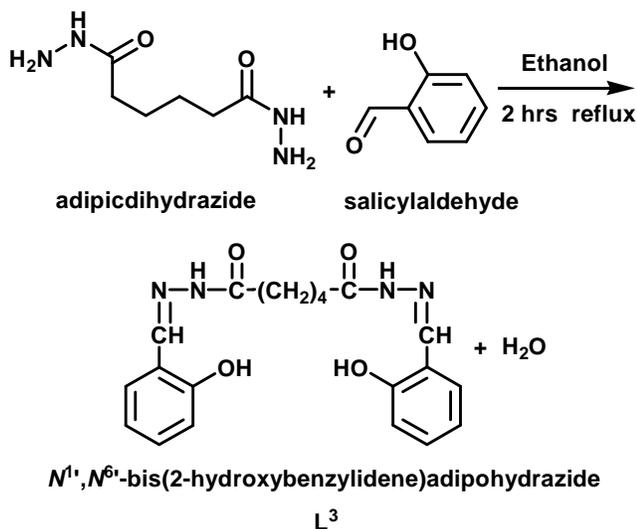
Synthesis of 3-((2,4-dimethylphenylimino)methyl)benzene-1,2-diol L²

Equimolar amount of 2,3-dihydroxybenzaldehyde and 2,4-dimethylaniline were dissolved in 50 ml of ethanol separately. Both solutions were mixed and the reaction mixture was refluxed for 3 hours. The solvent was evaporated by rotary evaporator and solid product obtained was recrystallized in chloroform:*n*-hexane (1:1).

Full Paper

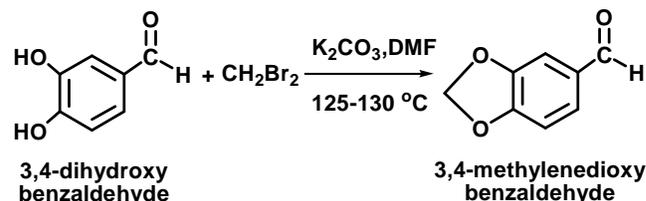
Synthesis of N¹,N⁶-bis(2-hydroxybenzylidene)adipohydrazide L³

3 mmol of the adipicdihydrazide and 6 mmol of salicylaldehyde were dissolved in 50 ml of ethanol separately. Both solutions were then mixed and refluxed for 2 hours with continuous stirring. The solution was cooled at room temperature. The solid product was filtered off and dried in air.

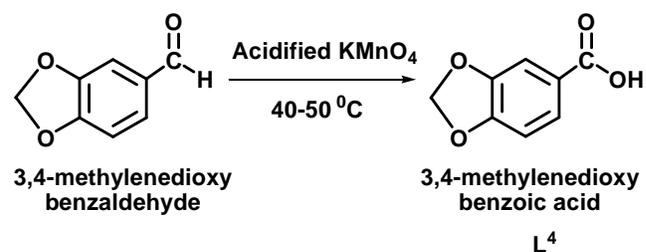
Synthesis of 3,4-methylenedihydroxybenzoic acid L⁴

A mixture of 22 mmol of 3,4-dihydroxybenzaldehyde, 27.5 mmol of dibromoethane, 23 mmol of potassium carbonate and 2 g CuO in 200 ml of DMF was heated under inert atmosphere at 130 °C for 2.5 hours. The cooled mixture was diluted with 65 ml of water and extracted with four equal portion of 50 ml benzene and dried over anhydrous K₂CO₃. The distillation un-

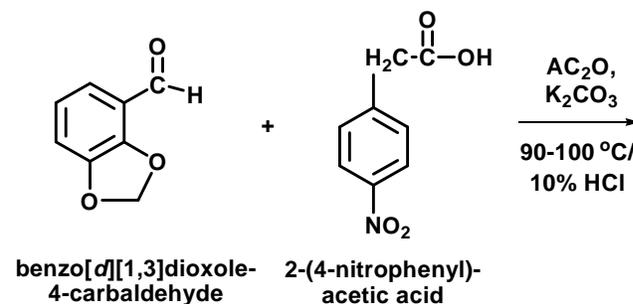
der reduce pressure gave 3.5 g of black residue. Vacuum distillation of black residue gives light yellow oil, which turns crystalline on solidification.

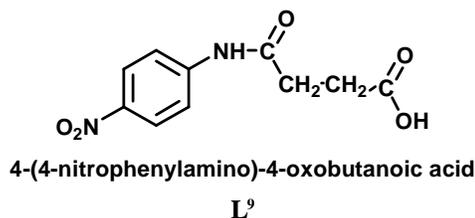
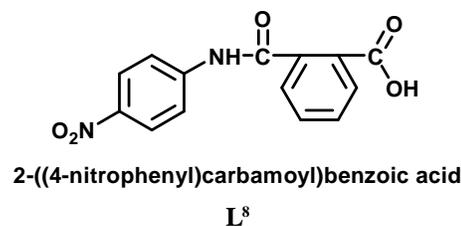
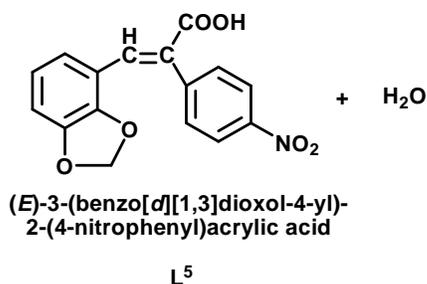


Then 3,4-methylenedihydroxybenzaldehyde was dissolved in water (30 ml) and the temperature was maintained at 40-50 °C. Aqueous solution of KMnO₄ (100 ml) was added until the odor of *m*-piperonal was no longer perceptible. The resultant mixture was then filtered, and the filtrate was acidified with dilute HCl the product was precipitated out, it was again filtered and washed out with water and dried.

Synthesis of (E)-3-(benzo[d][1,3]dioxol-4-yl)-2-(4-nitrophenyl)acrylic acid L⁵

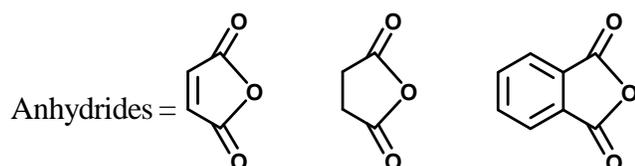
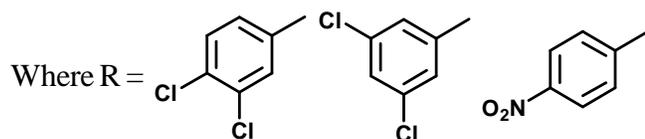
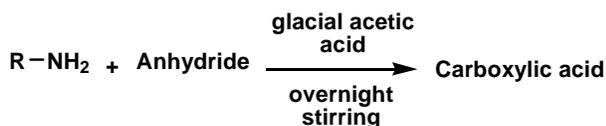
3.25 mmol of benzo[d][1,3]dioxol-4-carbaldehyde was added to the 2.3 mmol of 2-(4-nitrophenyl)acetic acid in 10 ml of acetic anhydride which act as dehydrating agent. Basic medium was provided by 1.3 mmol of K₂CO₃ dissolved in water. The temperature was slowly raised to 90-100 °C, sustained for 24 hours. After that 10% HCl and 20 ml of H₂O was added in hot solution and stirred for 2 hours at room temperature. The resultant mixture was filtered and washed with H₂O to ensure the complete removal of acetic anhydride.



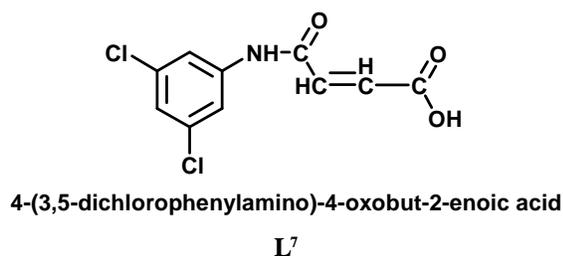
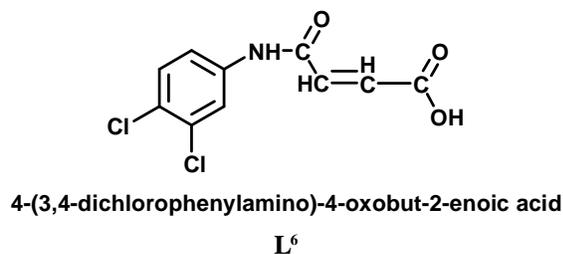


General procedure for the synthesis of ligands L⁶-L⁹

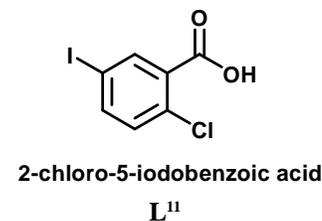
A solution of phthalic/maleic/succinic anhydride (1 mmol) in glacial acetic acid (300 ml) was added to the solution of substituted aniline in glacial acetic acid (150 ml) and the mixture was stirred at room temperature over night. The precipitates formed were filtered off, washed with cold distilled water (200 ml) and air dried.



Carboxylic acids

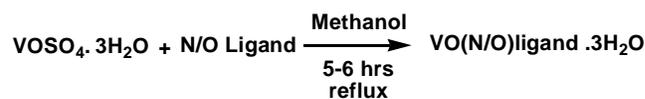


Purchased ligands L¹⁰, L¹¹



General procedure for the synthesis of complexes with N/O donor ligands

$\text{VO}(\text{SO}_4)_3 \cdot 3\text{H}_2\text{O}$ (1 mmol) was dissolved in 25 ml of methanol in a round bottom flask at room temperature and then added solution of ligand (1 mmol) dropwise on continuous stirring into it. The reaction mixture was refluxed over water bath for 5-6 hours. The solvent was evaporated by rotary evaporator and solid product obtained was dried in air.



Complex no.	Ligand
1	L ¹
2	L ²
3	L ³

General procedure for the formation of complexes with O-donor ligands

It has been carried out in two steps.

Step 1

Ligand solution (1 mmol) was suspended in water and equimolar amount of aqueous solution of NaHCO_3 was added into it drop wise with continuous stirring.

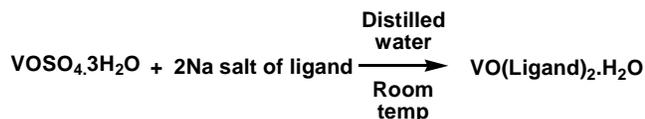
Full Paper

After 2 hours, the solvent was evaporated by rotary evaporator under reduced pressure and solid obtained was dried in air.



Step 2

Sodium salt of the ligand (1 mmol) was dissolved in distilled water and add $\text{VO}(\text{SO}_4)_2 \cdot 3\text{H}_2\text{O}$ (0.5 mmol) in portion and stirred the reaction mixture for 2 hrs at room temperature. Precipitates formed were filtered off and washed with distilled water and dried in air.



Complex no.	Ligand
4	L ⁴
5	L ⁵
6	L ⁶
7	L ⁷
8	L ⁸
9	L ⁹
10	L ¹⁰
11	L ¹¹

RESULTS AND DISCUSSION

The synthesized complexes are crystalline, colored and stable at room temperature and are soluble in common organic solvents. The physical properties and elemental analysis data of the ligands and complexes are reported in TABLES 1 and 2, respectively.

Conductance measurement

Conductance measurements of the ligands/sodium salt of ligands and their oxovanadium(IV) complexes were carried out at room temperature. The conductance of the solvent was deducted from the measured value. Ligands show high molar conductance as compared to synthesized complexes, indicating the non-electrolytic nature of the synthesized complexes^[28] (TABLE 3).

Infrared spectroscopy

Infra-red spectral data of the synthesized ligands and their oxovanadium complexes were recorded as

KBr discs, in the range 4000-400 cm^{-1} . The characteristic peaks for the ligands and their oxovanadium(IV) complexes were assigned and found in close agreement with the reported values in the literatures^[29,30]. The most important frequencies in the complexes are $\nu_{\text{asym}}(\text{COO})$, $\nu_{\text{sym}}(\text{COO})$, $\nu(\text{O-H})$, $\nu(\text{C=N})$, $\nu(\text{N-H})$, $\nu(\text{V=O})$ and $\nu(\text{V-O})$. The main bands in the infra-red spectra of ligands and the complexes are listed in the TABLE 4.

The characteristic peaks assigned to $\nu_{\text{asym}}(\text{COO})$ in the region 1586-1698 cm^{-1} in the free ligands shifted to lower frequencies, and the $\nu_{\text{sym}}(\text{COO})$, in the IR region 1364-1449 cm^{-1} shifted to higher frequencies in the complexes, showing the bidentate nature of the carboxylate group ligands in the complexes^[30]. The difference $\Delta\nu = [\nu_{\text{asym}}(\text{COO}) - \nu_{\text{sym}}(\text{COO})]$ helps in predicting the nature of the ligands in the complexes. The $\Delta\nu < 200 \text{ cm}^{-1}$ confirms the bidentate nature of the ligands^[31]. In case of N-donor ligands $\nu(\text{C=N})$ peaks that appears at 1609-1623 cm^{-1} shifted to lower values, showing

TABLE 1 : Physical properties of ligands and vanadyl(IV) complexes

Comp. No.	Mol. Formula	Mol. Wt	Color	% yield	m.p. °C
(L ¹)	C ₈ H ₇ N ₂ O ₂ Br	243.06	White	75	247-248
(1)	C ₈ H ₁₂ N ₂ O ₆ BrV	363.04	Brownish yellow	76	207-208
(L ²)	C ₁₅ H ₁₅ NO ₂	241.29	Brown	73	145
(2)	C ₁₅ H ₂₀ NO ₆ V	361.26	Dark Brown	72	180 dec.
(L ³)	C ₂₀ H ₂₂ N ₄ O ₄	382.41	White	71	> 300
(3)	C ₂₀ H ₂₇ N ₄ O ₈ V	502.39	Dark Brown	73	250 dec.
(L ⁴)	C ₈ H ₆ O ₄	166.13	White	74	128-129
(4)	C ₁₆ H ₁₂ O ₁₀ V	415.2	Green	68	> 300
(L ⁵)	C ₁₆ H ₁₁ NO ₆	313.26	Off-white	78	210
(5)	C ₃₂ H ₂₂ N ₂ O ₁₄ V	709.46	Green	65	200 dec.
(L ⁶)	C ₁₀ H ₇ NO ₃ Cl ₂	260.07	Light brown	77	185
(6)	C ₂₀ H ₁₄ N ₂ O ₈ Cl ₄ V	603.09	Green	65	205 dec.
(L ⁷)	C ₁₀ H ₇ NO ₃ Cl ₂	260.07	Light yellow	76	235
(7)	C ₂₀ H ₁₄ N ₂ O ₈ Cl ₄ V	603.09	Green	63	256
(L ⁸)	C ₁₄ H ₁₀ N ₂ O ₅	286.24	Off-white	77	100-101
(8)	C ₂₈ H ₂₀ N ₄ O ₁₂ V	655.42	Green	64	210 dec.
(L ⁹)	C ₁₀ H ₁₀ O ₅ N ₂	238.2	White	76	155-156
(9)	C ₂₀ H ₂₀ N ₄ O ₁₂ V	559.33	Green	66	> 300
(L ¹⁰)	C ₇ H ₇ NO ₂	137.14	White	-	100-101
(10)	C ₁₄ H ₁₄ N ₂ O ₆ V	357.21	Green	62	160 dec.
(L ¹¹)	C ₇ H ₄ O ₂ ICl	282.46	White	-	145-146
(11)	C ₁₄ H ₈ O ₆ Cl ₂ I ₂ V	647.87	Green	63	> 300

TABLE 2 : Elemental analysis data of vanadyl(IV) complexes

Compound No.	%C		%H		%N	
	Calcd.	Found	Calcd.	Found	Calcd.	Found
(L ¹)	39.53	39.57	2.90	2.94	11.53	11.49
(1)	26.47	26.43	3.33	3.37	7.72	7.76
(L ²)	74.67	74.63	6.27	6.31	5.81	5.85
(2)	49.87	49.91	5.58	5.62	3.88	3.92
(L ³)	62.82	62.78	5.80	5.84	14.65	14.69
(3)	47.81	47.85	5.42	5.38	11.15	11.11
(L ⁴)	57.84	57.80	3.64	3.68	-	-
(4)	46.28	46.24	2.91	2.95	-	-
(L ⁵)	61.35	61.31	3.54	3.58	4.47	4.43
(5)	54.17	54.13	3.13	3.17	3.95	3.98
(L ⁶)	46.18	46.22	2.71	2.67	5.39	5.42
(6)	39.83	39.87	2.34	2.30	4.65	4.69
(L ⁷)	46.18	46.22	2.71	2.75	5.39	5.43
(7)	39.83	39.79	2.34	2.30	4.65	4.69
(L ⁸)	58.74	58.70	3.52	3.56	9.79	9.83
(8)	51.31	51.35	3.08	3.12	8.55	8.59
(L ⁹)	50.42	50.46	4.23	4.27	11.76	11.72
(9)	42.95	42.99	3.60	3.64	10.02	10.06
(L ¹⁰)	61.31	61.35	5.14	5.10	10.21	12.7
(10)	47.07	47.11	3.95	3.91	7.84	7.80
(L ¹¹)	29.76	29.80	1.43	1.47	-	-
(11)	25.95	25.91	1.24	1.28	-	-

TABLE 3 : Conductance measurement of ligands and vanadyl(IV) complexes

Ligand No.	Conductance Scm ² /mol	Compound No.	Conductance Scm ² /mol
(L ¹)	3.24	(1)	13.09
(L ²)	2.50	(2)	18.90
(L ³)	3.60	(3)	4.47
(L ⁴ Na)	82.70	(4)	2.08
(L ⁵)	79.33	(5)	5.53
(L ⁶ Na)	66.03	(6)	5.23
(L ⁷ Na)	87.93	(7)	1.84
(L ⁸ Na)	85.40	(8)	4.96
(L ⁹ Na)	127.50	(9)	7.59
(L ¹⁰ Na)	79.50	(10)	3.39
(L ¹¹ Na)	106.50	(11)	3.62

the complexation through N. The appearance of new sharp bands in the range 990-903 and 578-504 cm⁻¹ due to ν V=O and ν V-O, respectively, confirms the complexation. The O-H stretching of water is observed in the range of 3415-3467 cm⁻¹[31].

Thermal analysis

Thermal analysis of complex 5 shows fragmentation in three steps. First is from 178 to 245 °C, second is from 292 to 375 °C and the third is from 377 to 499 °C. The observed weight loss 19.14%, 25.61% and

TABLE 4 : IR spectral data of ligands and vanadyl(IV) complexes (cm⁻¹)

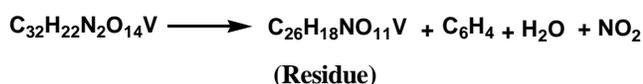
Comp. No.	ν (O-H)	ν (N-H)	ν (C=O)	ν (C=N)	ν (V=O)	ν (V-O)	$\nu_{\text{asym}}(\text{COO})$	$\nu_{\text{sym}}(\text{COO})$	$\Delta\nu$
(L ¹)	-	3185	1706	1609	-	-	-	-	-
(1)	3415	-	-	1584	990	504	-	-	-
(L ²)	-	-	-	1623	-	-	-	-	-
(2)	3428	-	-	1598	974	575	-	-	-
(L ³)	-	3201	1668	1616	-	-	-	-	-
(3)	3425	-	-	1599	940	575	-	-	-
(L ⁴)	-	-	-	-	-	-	1672	1449	223
(4)	3467	-	-	-	903	554	1656	1532	124
(L ⁵)	-	3263	1704	-	-	-	1648	1378	270
(5)	3420	3269	1707	-	977	551	1629	1471	158
(L ⁶)	-	3560	1700	-	-	-	1650	1390	260
(6)	3427	3269	1708	-	975	578	1629	1470	159
(L ⁷)	-	-	-	-	-	-	1698	1420	278
(7)	3432	-	-	-	925	561	1678	1484	194
(L ⁸)	-	3342	1714	-	-	-	1635	1364	271
(8)	3447	-	1718	-	982	561	1552	1407	145
(L ⁹)	-	-	-	-	-	-	1693	1432	261
(9)	3452	-	-	-	972	565	1567	1460	107

Full Paper

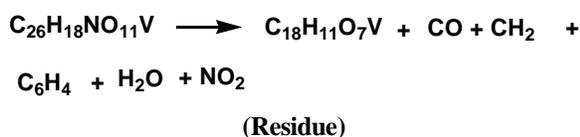
Comp. No.	$\nu(\text{O-H})$	$\nu(\text{N-H})$	$\nu(\text{C=O})$	$\nu(\text{C=N})$	$\nu(\text{V=O})$	$\nu(\text{V-O})$	$\nu_{\text{asym}}(\text{COO})$	$\nu_{\text{sym}}(\text{COO})$	$\Delta\nu$
(L ¹⁰)	-	3362	1752	-	-	-	1586	1440	146
(10)	3416	3341	1700	-	986	561	1545	1441	104
(L ¹¹)	-	-	-	-	-	-	1685	1425	260
(11)	3425	-	-	-	983	559	1653	1550	103

50.76%, are in good agreement with the theoretical weight loss of 19.74%, 25.38% and 47.53%, respectively. Following are the proposed fragmentations in various ranges:

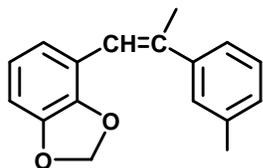
Step 1



Step 2



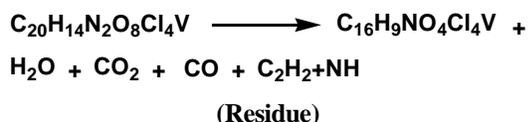
Step 3



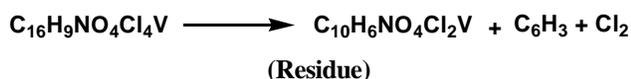
(Residue)

Thermal analysis of complex 6 shows three steps decomposition. First step starts at 139 °C and extends up to 219 °C, second step covers the temperature range of 222-292 °C and the third step shows degradation at 296-538 °C. The observed weight loss 21.58%, 22.20% and 46.59% are in good agreement with the theoretical weight loss of 21.72%, 24.21% and 43.00%, respectively. The thermogravimetric data is summarized in TABLE 5.

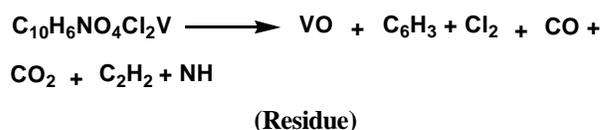
Step 1



Step 2

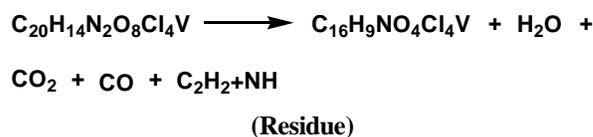


Step 3

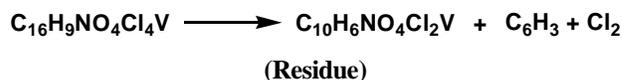


Thermal analysis of complex 7 shows decomposition in three steps, first at 115-207 °C, second at 208-276 °C and third at 279-522 °C with the observed weight loss of 20.30%, 24.36% and 41.0% which are in good agreement with the theoretical weight loss of 21.72%, 24.21% and 40.29%, respectively.

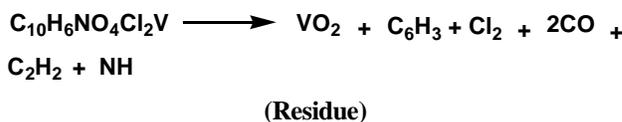
Step 1



Step 2



Step 3



Thermogravimetric data of complex 11 shows single step fragmentation, starting from 163 °C and extend up to 411 °C. The observed weight loss 78.19 % is in good agreement with the theoretical weight loss of 77.93%. The observed weight 21.80 % of residue is almost equal to the theoretical weight 22.06 %. The proposed fragmentations can be shown by the following step:

Step 1

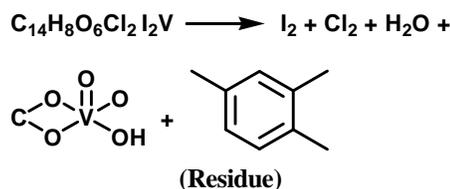


TABLE 5 : Thermogravimetric data of vanadyl(IV) complexes

Comp. no.	Compound	Temp. range °C	Evolved components	% wt loss obs.	% wt loss calcd.	Residue % observed (calcd.)
5	C ₃₂ H ₂₂ N ₂ O ₁₄ V	178-287	H ₂ O, C ₆ H ₄ , NO ₂	19.14	19.74	V
		292-375	H ₂ O, C ₆ H ₃ , CO, CH ₂	25.61	25.38	7.19
		377-499	H ₂ O, C ₆ H ₄ , 2CO ₂ , 2CO, C ₆ H ₃ , C ₂ H	50.76	47.53	(6.93)
6	C ₂₀ H ₁₄ N ₂ O ₈ VCl ₄	139-219	H ₂ O, CO ₂ , C ₂ H ₂ , NH, CO	21.58	21.72	VO
		222-292	C ₆ H ₃ , Cl ₂	22.2	24.21	12.19
		296-538	C ₆ H ₃ , Cl ₂ , CO ₂ , NH, C ₂ H ₂ , CO	46.59	43	(11.11)
7	C ₂₀ H ₁₄ N ₂ O ₈ VCl ₄	115-207	H ₂ O, CO ₂ , CO, C ₂ H ₂ , NH	20.30	21.72	VO ₂
		208-276	C ₆ H ₃ , Cl ₂	24.36	24.21	14.70
		279-522	C ₆ H ₃ , Cl ₂ , 2CO, NH, C ₂ H ₂	41.0	40.29	(13.7)
11	C ₁₄ H ₈ Cl ₂ O ₆ I ₂ V	163-411	C ₆ H ₃ , C, H ₂ O, I ₂ , Cl ₂	78.19	77.93	VO ₅ C 21.80 (22.06)

Semi-empirical study

In the complex 2, the ligand bind in bidentate (N,O) fashion together with a terminal oxo ligand and three water molecules. The modeled structure show distorted octahedral geometry around vanadium. The apical vanadium oxygen distance is 1.57 Å. The V(IV)-O bond lengths for coordinated water molecules in the equatorial plane are 2.20 Å and 2.34 Å, respectively. The V-O (eq. lig) bond length is 1.96 Å, while the V-N (eq. lig) is 2.06 Å. The long V(IV)-O bond length in the axial position 2.54 Å, may be due to the trans influence of the oxo group. The O(apical)-V-O(lig) angles is 109.1 and O(apical)-V-N(lig) is 106.2°, while the apical O-V-O(H₂Oeq) angles are 109.1 and 98.4°. The vanadium ion is 0.61 Å above the mean equatorial plane formed by the three oxygen atoms and one nitrogen-coordinating atom. The N(eq.lig)-O(eq.lig) bite distance is 2.85 Å.

In complex 4, the modeled structure shows distorted octahedral geometry around vanadium atom. The apical vanadium oxygen bond length is 1.55 Å. The V(IV)-O bond lengths for coordinated water molecules in the equatorial plane are 2.23 and 2.14 Å, respectively. The longer V(IV)-O bond length in the axial position is 2.75 Å may be due to the trans influence of the oxo group. The V-O(eq)(lig) bond length is 2.19 and 2.13 Å. The O(apical)-V-O(lig) angles are 109.9 and 108.0°, while the apical O-V-O(H₂O) angles are 104.1 and 106.8°. The O(eq.lig)-O (eq.lig) bite distance is 2.18 Å. The vanadium ion is 0.64 Å above the mean

equatorial plane formed by the four oxygen-coordinating atoms.

In the modeled complex 7, the two carboxylate ligands bind in bidentate (O,O) fashion and exhibit distorted octahedral geometry around vanadium. The apical vanadium oxygen distance is 1.55 Å. The V-O (eq. lig) bond is 2.17, 2.17, 2.31 and 2.31 Å. The longer V(IV)-O(H₂O) bond length in the axial position 2.55 Å, may be due to the trans influence of the oxo group. The O(apical)-V-O(lig) angles are 105.7, 105.9, 106.1 and 106.2°, while the apical O-V-O(H₂O) angle is 151.3°. The vanadium ion is 0.61 Å above the mean equatorial plane formed by the four coordinating oxygen atoms. The O(eq.lig)-O(eq.lig) bite distance is 2.19 Å.

In complex 9, the two carboxylate ligands bind in bidentate (O,O) manner together with a terminal oxo ligand and one water molecule in order to complete the metal coordination sphere. The modeled structure show distorted octahedral geometry around vanadium atom. The apical vanadium oxygen distance is 1.55 Å. The V-O (eq. lig) bond length is 2.18 and 2.29 Å. The long V(IV)-O(H₂O) bond length in the axial position is 2.63 Å, which may be due to the trans influence of the oxo group. The O(apical)-V-O(lig) angles are 106.6, 107.1, 107.3 and 106.9°, while the apical O-V-O(H₂O) angle is 151.1°. The vanadium ion is 0.65 Å above the mean equatorial plane formed by four oxygen atoms. The O(eq.lig)-O(eq.lig) bite distance is 2.18 Å.

In the modeled structure of complex 10, the two carboxylate ligands bind in bidentate fashion and show

Full Paper

distorted octahedral geometry around vanadium. The apical vanadium oxygen distance is 1.55 Å. The V-O (eq. lig) bond length is 2.33, 2.16, 2.16 and 2.33 Å. The longer V(IV)-O(H₂O) bond length in the axial position is 2.54 Å, which may be due to the trans influence of the oxo group. The O(apical)-V-O(lig) angles are 105.1, 106.0, 105.6, 106.0°, while the apical O-V-O(H₂O) angle is 150.9°. The vanadium ion is 0.61 Å above the mean equatorial plane formed by the four coordinating oxygen atom. The O(eq.lig)-O(eq.lig) bite distance is 2.19 Å.

The modeled structure of complex XI, show the distorted octahedral geometry around vanadium. The apical vanadium oxygen distance is 1.56 Å. The V-O (eq. lig) bond is 2.16, 2.28 Å. The long V(IV)-O(H₂O) bond length in the axial position 2.65 Å, may be due to the trans influence of the oxo group. The O(apical)-V-O(lig) angles are 106.8, 106.8, 106.8 and 106.9°, while the apical O-V-O(H₂O) angle is 152.6°. The vanadium ion is 0.64 Å above the mean equatorial plane formed by the four coordinating oxygen atoms. The O(eq.lig)-O(eq.lig) bite distance is 2.18 Å. The bond lengths and bond angles for all non-hydrogen atoms are given in TABLE 6. The geometry optimised structures are given in Figures 1-6. The calculated values are close to typical values of similar complexes in literature^[32-35].

TABLE 6 : Selected bond lengths and bond angles of vanadyl(IV) complexes

Complex 2							
C5	C4	1.43		N2	C17	1.44	
V1	N2	2.06		V1	O10	1.96	
O34	V1	2.20		V1	O37	2.34	
O40	V1	1.57		O41	V1	2.54	
N2	V1	O10	90.2	N2	V1	O34	86.7
N2	V1	O37	150.9	O10	V1	O34	136.9
O10	V1	O40	113.0	C3	N2	V1	116.9
N2	V1	O40	106.2	O10	V1	O37	65.6
O40	V1	O41	159.6	C9	O10	V1	115.3
Complex 4							
C18	C19	1.41		C19	C11	1.40	
V1	O2	2.14		V1	O5	2.23	
V1	O8	2.19		V1	O10	2.13	
O25	V1	1.55		O26	V1	2.75	
O2	V1	O5	69.2	O2	V1	O8	143.0

O5	V1	O10	147.9	O5	V1	O25	104.1
O25	V1	O26	150.3	C9	O8	V1	91.0
C9	O10	V1	93.8	O5	V1	O8	105.7
C17	C18	C19	116.3	C18	C19	C11	121.6
Complex 7							
V1	O67	2.31		V1	O34	2.31	
V1	O68	1.55		V1	O69	2.55	
C22	C21	1.41		O30	N29	1.22	
O31	N29	1.22		V1	O2	2.17	
O2	V1	O35	111.4	O2	V1	O67	148.2
O2	V1	O34	58.4	O2	V1	O68	106.2
O34	V1	O68	105.9	O34	V1	O69	61.9
C57	C58	C59	119.2	C58	C59	C54	120.2
C57	N62	O63	117.8	O63	N62	O64	124.6
Complex 9							
C17	O29	1.28		C17	O16	1.28	
V1	O2	2.18		V1	O16	2.18	
V1	O29	2.29		V1	O15	2.29	
O30	V1	1.55		O31	V1	2.63	
O2	V1	O29	145.8	O2	V1	O15	58.6
O2	V1	O30	106.9	O2	V1	O31	89.2
O16	V1	O29	58.6	O16	V1	O15	146.3
C5	C6	C7	121.3	C5	C6	I13	119.5
O15	V1	O31	61.2	O30	V1	O31	151.1
Complex 10							
C32	C31	1.53		C31	C29	1.50	
V1	O28	2.16		O30	V1	2.33	
O54	V1	1.55		V1	O55	2.54	
V1	O2	2.16		V1	O4	2.33	
O2	V1	O30	148.0	O2	V1	O54	106.0
O2	V1	O55	89.5	O4	V1	O28	149.3
C29	O28	V1	95.6	O30	C29	O28	117.4
C29	O30	V1	88.3	C32	C31	C29	111.4
C38	C39	C40	120.7	C38	C39	N44	119.6
Complex 11							
C3	O2	1.30		C3	O17	1.28	
V1	O2	2.16		V1	O18	2.16	
V1	O33	2.28		V1	O17	2.28	
O34	V1	1.56		O35	V1	2.65	
O2	V1	O18	109.9	O2	V1	O33	146.4
O2	V1	O17	58.9	O2	V1	O34	106.9
O2	V1	O35	88.3	O18	V1	O33	58.9
C21	C20	C19	118.5	C25	C20	C19	122.5
C20	C21	C22	121.2	C21	C22	C23	119.6

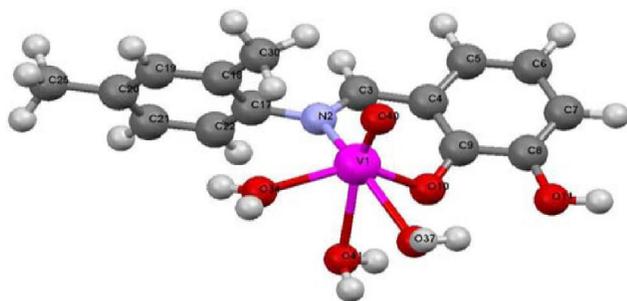


Figure 1 : Geometry optimised structure of complex 2

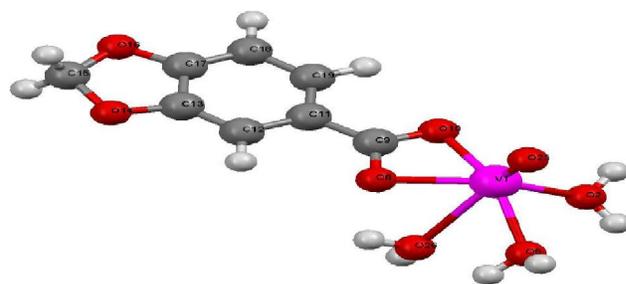


Figure 2 : Geometry optimised structure of complex 4

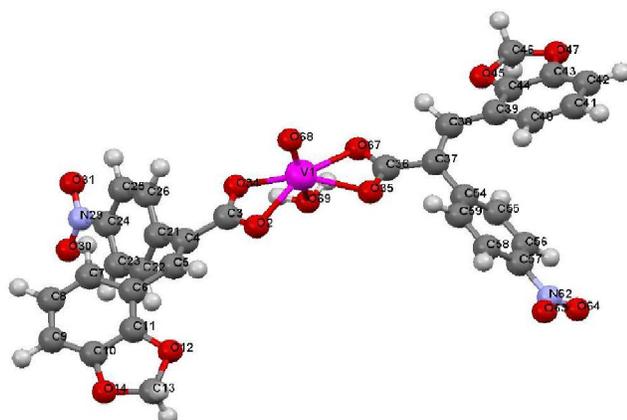


Figure 3 : Geometry optimized structure of complex 7

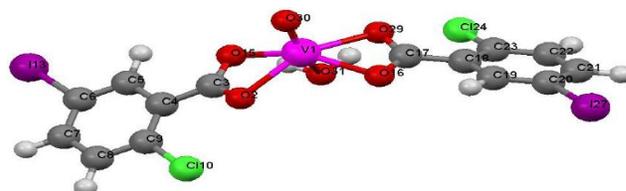


Figure 4 : Geometry optimised structure of complex 9

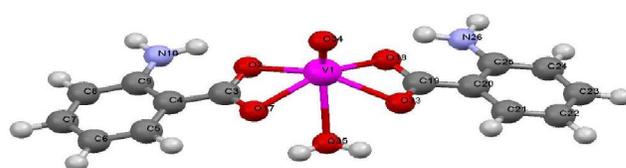


Figure 6 : Geometry optimized structure of complex 11

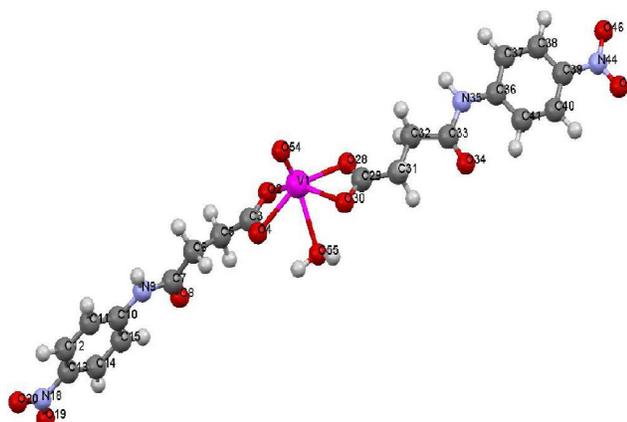


Figure 5 : Geometry optimized structure of complex 10

Alkaline phosphatase activity

The alkaline phosphatase activity was checked by monitoring the rate of hydrolysis of *p*-nitrophenyl phosphate at 25 °C in 0.1 M Na₂CO₃-NaHCO₃ (sodium carbonate–bicarbonate) buffer (pH 10.1)^[36].

The enzyme catalyzes the hydrolysis of phosphate monoesters to give inorganic phosphate and an alcohol. The identity of the alcohol varies depending on the specific phosphatase, and could be some small organic molecule such as a nucleotide (the building blocks of nucleic acids) or an amino acid in a protein (a serine,

tyrosine, or threonine).

The assay of alkaline phosphatase activity takes advantage of the fact that the enzyme is non-specific, and utilizes the non-biological substrate *p*-nitrophenyl phosphate (colourless) to give yellow coloured *p*-nitrophenol upon hydrolysis which helps to monitor the reaction.

Alkaline phosphatase activity in the presence and absence of inhibitor was measured spectrophotometrically using *p*-nitrophenyl phosphate as the substrate. The release of yellow colour *p*-nitrophenol chromophore was monitored at 405 nm wavelength. Enzyme activity is expressed as the μM of *p*-nitrophenol released per minute. By the addition of inhibitor the activity of the enzyme decreases and at higher concentration it is completely inhibited in some cases as shown in Figures 7 and 8.

The inhibitory effect of vanadate on alkaline phosphatase activity mirrors a competitive mode of inhibition that is characteristic of VO₄^[36,37]. Due to the structural and electronic similarity of vanadate with inorganic phosphate, vanadate may have distorted configuration with the active site of alkaline phosphatase activity^[38], thereby resulting in a very slow rate of formation and breakdown of enzyme substrate complex.

Full Paper

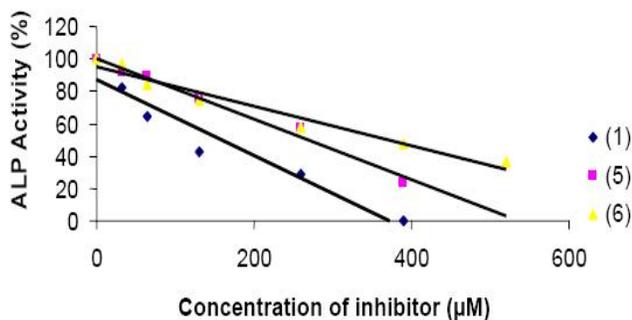


Figure 7 : Effect of inhibitor on the activity of the enzyme for complex 1, 5 and 6

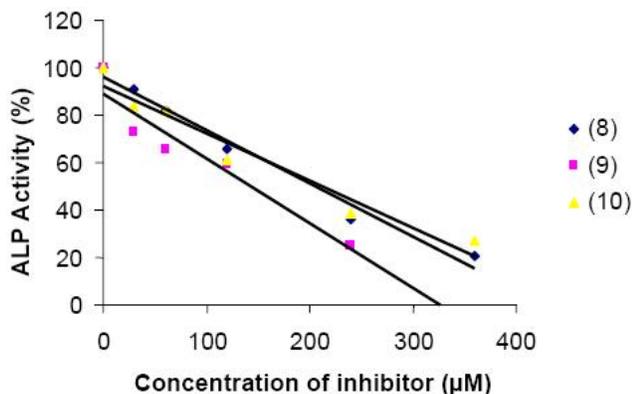


Figure 8 : Effect of inhibitor on the activity of the enzyme for complex 8, 9 and 10

CONCLUSION

Stoichiometric amounts of ligands and $\text{VO}_2 \cdot 3\text{H}_2\text{O}$ in methanol/water under reflux/room temperature yields oxovanadium(IV) complexes in quantitative yield. In IR spectra appearance of new sharp bands in the range $990\text{-}903$ and $578\text{-}504\text{ cm}^{-1}$ due to $\nu\text{V}=\text{O}$ and $\nu\text{V}-\text{O}$, respectively, confirms the complexation. The lowering of $\nu_{\text{asym}}(\text{COO})$ vibrational frequency and rising of $\nu_{\text{sym}}(\text{COO})$ frequency of carboxylate group is indicative for the bidentate nature of the carboxylate group. Thermogravimetric analysis data demonstrate that decomposition begins above $100\text{ }^\circ\text{C}$ and extend up to $538\text{ }^\circ\text{C}$, with the removal of gaseous products and the theoretical weight loss are in close agreement with experimentally observed weight loss. The molar conductivities of the complexes are observed in the range of $1.84\text{-}18.90\text{ Scm}^2\text{mol}^{-1}$ indicating the non-ionic character of the complexes. The alkaline phosphatase activity in the presence and absence of inhibitor shows that by the addition of inhibitor, the activity of enzyme decreases and at higher concentration it is completely inhibited.

ACKNOWLEDGEMENTS

SA is thankful to Quaid-i-Azam University, Islamabad and Pakistan Science Foundation, Islamabad for financial support. SKS and KQ thanks the Head, App Sci. and Dean FET, MITS for encouragement and support.

REFERENCES

- [1] D.C.Crans, J.J.Smee, E.Gaidamauskas, L.Q.Yang; *Chem.Rev.*, **104**, 849 (2004).
- [2] Y.Shechter, I.Goldwasser, M.Mironchik, M.Fridkin, D.Gefel; *Coord.Chem.Rev.*, **237**, 3 (2003).
- [3] G.Y.Yeh, D.M.Eisenberg, T.J.Kaptchuk, R.S.Phillips; *Diabetes Care*, **261**, 277 (2003).
- [4] H.Sakurai, H.Yasui, Y.Adachi; *Expert.Opin. Investig.Drugs*, **12**, 1189 (2003).
- [5] A.Butler, C.J.Carrano; *Coord.Chem.Rev.*, **109**, 61 (1991).
- [6] D.Rehder; *Inorg.Chem.Commun.*, **6**, 604 (2003).
- [7] K.H.Thompson, J.H.McNeill, C.Orvig; *Chem.Rev.*, **99**, 2561 (1999).
- [8] A.B.Goldfine, G.Willksy, C.R.Kahn; in: A.S.Tracey, D.C.Crans, (Eds); 'Vanadium Compounds: Biochemistry, Chemistry, and Therapeutic Applications', ACS Symposium Series, American Chemical Society: Washington DC, **711**, (1998).
- [9] C.Bolm; *Coord.Chem.Rev.*, **237**, 242 (2003).
- [10] S.Bunce, R.J.Cross, L.J.Farrugia, S.Kunchandy, L.L.Meason, K.W.Muir, M.O'Donnell, R.D.Peacock, D.Stirling, S.J.Teate; *Polyhedron*, **23**, 4179 (1998).
- [11] J.R.Zamian, E.R.Dockal, G.Castellano, G.Oliva; *Polyhedron*, **14**, 2411 (1995).
- [12] J.R.Zamian, E.R.Dockal; *Transition Met.Chem.*, **21**, 370 (1996).
- [13] A.P.A.Marques, E.R.Dockal, I.L.V.Rosa; in: Proceedings of the 11th Congresso Brasileiro de Cata'lise and 1st Congresso de Cata'lise do Mercosul, Bento Goncalves, RS, 16-19 September, **2**, 803 (2000).
- [14] A.P.A.Marques; Ph.D. Thesis, Universidade Federal de Sa'õ Carlos, Brazil, (2002).
- [15] A.P.A.Marques, E.R.Dockal, I.L.V.Rosa; in: Proceedings of the 5th European Biological Inorganic Chemistry Conference, Toulouse, I.L.V.Rosa, (Ed); <http://www.lcc-toulouse.fr/eurobic5.html>; 17-20 July, (2000).

- [16] A.Kozlov, K.Asakura, Y.Iwasawa; *Micropor. Mesopor.Mat.*, **21**, 571 (1998).
- [17] D.Mansuy; *Coord.Chem.Rev.*, **125**, 129 (1993).
- [18] K.D.Karlin; *Science*, **261**, 701 (1993).
- [19] F.Bedioui; *Coord.Chem.Ver.*, **144**, 39 (1995).
- [20] I.Stiefel; in: J.Reedijk, E.Bouwman, (Eds); 'Bioinorganic Catalysis', Marcel Dekker: New York, (1999).
- [21] S.K.S.Hazari, J.Kopf, D.Palit, S.Rakshit, D.Rehder; *Inorg.Chim.Acta*, **362**, 1343 (2009).
- [22] T.Ghosh, B.Mondal, T.Ghosh, M.Sutradhar, G.Mukerjee, M.G.B.Drew; *Inorg.Chim.Acta*, **360**, 1753 (2007).
- [23] H.Yue, D.Zhang, Z.Shi, S.Feng; *Inorg.Chim.Acta*, **360**, 2681 (2007).
- [24] N.Muhammad, S.Ali, S.Shahzadi, A.N.Khan; *Russian J.Coord.Chem.*, **34**, 448 (2008).
- [25] W.L.F.Armarego, C.L.L.Chai; 'Purification of Laboratory Chemicals', 5th Edition, Butterworth-Heinemann: London, New York, (2003).
- [26] MOPAC2007, J.J.P.Stewart; *Stewart Computational Chemistry*, Version 7.334W.
- [27] J.J.P.Stewart; *J.Mol.Mod.*, **13**, 1173 (2007).
- [28] R.K.Agerwal, L.Singh, D.K.Sharma, R.Singh; *Turk.J.Chem.*, **29**, 309 (2005).
- [29] D.L.Pavia, G.M.Lampman, G.S.Kirtz; 'Introduction to Spectroscopy', Thomson Learning: USA, (2001).
- [30] O.A.Odunola, J.A.O.Woods; *Synth.React.Inorg. Met.-Org.Chem.*, **31**, 247 (2001).
- [31] G.B.Deacon, R.J.Philips; *Coord.Chem.Rev.*, **33**, 227 (1980).
- [32] M.Magnussen, T.Brock-Nannestad, J.Bendix; *Acta Cryst.*, **C63**, m51 (2007).
- [33] T.S.Guan, N.C.Hee, T.F.Lai, L.E.Khoon, S.M.Mansor, P.Balraj, T.L.Chu, B.M.Yamin, S.W.Ng; *Modern Appl.Sci.*, **2**, 117 (2008).
- [34] S.J.Kavitha, K.Panchanatheswaran, J.N.Low, C.Glidewell; *Acta Cryst.*, **C62**, m116 (2006).
- [35] F.Belaj, A.Basch, U.Muster; *Acta Cryst.*, **C56**, 921 (2000).
- [36] J.Ahlers; *Biochem.J.*, **149**, 535 (1975).
- [37] S.P.Shirazi, R.B.Beechey, P.J.Butterworth; *Biochem.J.*, **194**, 803 (1981).
- [38] K.M.Holtz, B.Stec, E.R.Kantrowitz; *J.Biol.Chem.*, **27**, 8351 (1999).