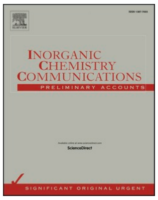
Inorganic Chemistry Communications 128 (2021) 108561

Contents lists available at ScienceDirect

Inorganic Chemistry Communications

journal homepage: www.elsevier.com/locate/inoche



Short communication

A novel anionic di-oxido vanadium(V) Schiff base complex: Synthesis, spectral characterization, X ray crystal structure, catalytic activity for the preparation of tetrahydro-4H-chromene derivatives and antibacterial properties

Mehrji Khosravan [a], Leila Abdolahi [a,b], S. Yousef Ebrahimipour [a,*]

[a] Department of Chemistry, Faculty of Science, Shahid Bahonar University of Kerman, Kerman, Iran
[b] Young Researchers Society, Shahid Bahonar University of Kerman, Iran, P.O. Box 76175-133, Kerman, Iran

ARTICLE INFO

Keywords:
Schiff base
Vanadium(V) complex
Antibacterial activity
Catalytic properties

ABSTRACT

In this work, a tridentate ONO Schiff base ligand,1-[(((2-hydroxyphenyl)imino)methyl)]naphthalen-2-ol [H_2L] and its di-oxido vanadium(V) complex [(VO_2(L)](NHET$_3$) have been synthesized and fully characterized using elemental analysis, molar conductivity and FT-IR, UV–Vis, and ^{1}HNMR spectroscopies. Single crystal X-ray diffraction was also used to accomplish the crystal structure of di-oxido vanadium(V) complex. The catalytic activity of the complex was also evaluated for the synthesis of tetrahydro-4H-chromene derivatives. The synthesized [VO_2(L)](NHET$_3$) complex showed superior catalytic characteristics in comparison to the previously reported catalysts. Furthermore,the antimicrobial properties of the complex against both gram-positive and gram-negative pathogens were evaluated, that an enhanced antibacterial activity was obtained with MIC values in the range of 100–200 μg/ml.

1. Introduction

Schiff bases derived from the reaction of primary amines and aldehydes have gained extensive interest due to their widespread applications. Schiff bases as polydentate ligands can form stable complexes with transition metals with versatile and tunable structures which have distinct catalytic and biologic activities [1–4]. The presence of azomethine (—N=CH) bond in Schiff bases is the crucial factor for the formation of stable complexes with transition metals [5]. An extensive library of Schiff bases have been synthesized and complexed with transition metal ions with potential applications in medicine and industry (catalysis and anticorrosion) [6–17]. Among the studied metals, vanadium complexes have gained much attention not only for their catalytic activities but also due to their antibacterial, anticancer, and other medicinal applications [8,18–21]. Vanadium complexes can act as the catalyst in several industrially important oxidation, epoxidation, and hydroxylation processes [22,23]. Also, it has crucial roles in many immune-related pathways in biological systems [24–26]. It is believed that the ability of vanadium to exist in three different forms and oxidation states is responsible for its physiological characteristics [27].

Recognizing the importance of both biological and industrial aspects, herein, we reported a di-oxido vanadium(V) Schiff base-complex using 1-[(((2-hydroxy)phenyl)imino)methyl]naphtalen-2-ol, [H_2L] as the ligand. [H_2L] and the [VO_2(L)](NHET$_3$) complex have been synthesized and characterized using UV–Vis, FT-IR, and ^{1}HNMR spectroscopies while the crystal structure of complex was evaluated using X-ray crystal diffraction. Finally, the catalytic performance of the [VO_2(L)](NHET$_3$) complex was evaluated in the synthesis process of tetrahydro-4H-chromenes. In addition, the biological activity of the parent ligand and the vanadium complex were evaluated against four different gram-positive and gram-negative pathogens. The synthesized compounds are stable at room temperature. They are soluble in most organic solvents including DMSO, DMF, methanol and ethanol and less soluble in other common solvents like dichloromethane, acetonitrile and insoluble in toluene, benzene and *n*-hexane. The molar conductivity value of the synthesized complex in EtOH shows that it is an 1:1 type electrolyte. In the asymmetric unit of the complex, two [VO_2(L)] (NHET$_3$) species exist. Figs. 1 and S1 depict the perspective view of these species and the assymetric unit of the crystal, respectivley. Also, Table S2 represents some selected bond distances and interbond angles. To determnine the

---

* Corresponding author at: Department of Chemistry, Faculty of Science, Shahid Bahonar University of Kerman, 76169-14111 Kerman, Iran.
E-mail address: ebrahimipour@uk.ac.ir (S.Y. Ebrahimipour).

https://doi.org/10.1016/j.inoche.2021.108561
Received 20 January 2021; Received in revised form 4 March 2021; Accepted 6 March 2021

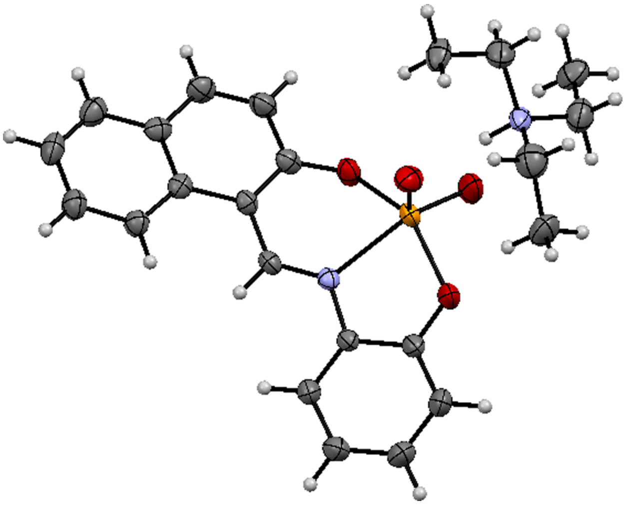


Fig. 1. Perspective view of $[VO_2(L)]$ $(NHET_3)$.

Table 1
Three component reaction of dimedone, malononitrile and aromatic aldehydes.

Entry	Ar	Time (min)	Yield (%)	M.p. (°C)	
				Found	Reported
1a	C_6H_5	45	97	231–233	231–232 [29]
1b	4-Cl-C_6H_4	45	95	214–216	215–217 [29]
1c	3-NO_2-C_6H_4	50	87	216–218	217–219 [31]
1d	2,4-(Cl)$_2$-C_6H_3	55	88	176–178	175–178 [29]
1e	4-CH_3-C_6H_4	50	85	217–219	218–220 [29]

Table 2
Comparison between previous catalysts used for the synthesis of 2-amino-7,7-dimethyl-5-oxo-4-phenyl-5,6,7,8-tetrahydro-4H-chromene-3-carbonitrile and $[VO_2(L)](NHET_3)$ used in this study.

Catalyst	Reaction conditions	Time (min)	Yield (%)	Reference
[VO(L)(phen)]	EtOH, reflux	20	90	[29]
Triethylbenzylammonium chloride	H_2O, 90 °C	240	90	[32]
K_3PO_4	EtOH, stirred	45	94	[31]
[Cu(L′)(Imi)] (8%mol)^a	EtOH, 50 °C	20	92	[2]
Tetrabutylammonium bromide	EtOH, reflux	20	92	[33]
$[VO_2(L)](NHET_3)$	Acetonitrile, 50 °C	45	97	This work

geometry of the pentacoordinated complexes, trigonality index (τ_5) described by Addison et al. is calculated [28]. $\tau_5 = 0$ indicates an ideal square–pyramid while $\tau_5 = 1$ indicates an ideal trigonal bipyramid. The values of τ_5 for $[VO_2(L)]$ $(NHET_3)$ (1) and $[VO_2(L)]$ $(NHET_3)$ (2) were calculated to be 0.21 and 0.14, respectively, confirming the distorted square pyramidal geometry of both molecules in the assyemtric unit. In the structure of the complex, the coordination sphere of the vanadium ion are occupied by two oxido groups (in *cis*-position) and ONO donor atoms of the dianionic Schiff base ligand. The nitrogen atom of the imino group and the oxygen atoms of the naphtholate and phenolate groups are the donor atoms of the deporotonated Schiff base $[L^{2-}]$.

In the complex structure, the triethylammonium cation is strongly bonded to the apical oxygen atom via hydrogen bonding. According to the obtained results (Fig. S2), the FT-IR spectrum of $[H_2L]$ ligand showed a vibrational band at 1630 cm^{-1}, which can be attributed to the C=N group and approved the formation of a Schiff base ligand. The tensile vibration of OH and vibration band of C=C in the aromatic rings can be seen at 3447 cm^{-1} and 1406–1459 cm^{-1}, respectively. After complexation, the frequency of the mentioned azomethine (C=N) band at 1630 cm^{-1} decreased to 1615 cm^{-1} [8]. Two absorption bands observed at 987 cm^{-1} and 824 cm^{-1} are attributed to the symmetric and asymmetric stretching vibration bands of *cis*-VO_2, respectively [18]. In addition, the vibrations appeared at 459 cm^{-1}, 506 cm^{-1} and 2977 cm^{-1} can be related to the V—N, V—O, and N—H bonds, respectively. Two absorption bands at 2496 cm^{-1} and 2602 cm^{-1} were also ascribed to CH_2 and CH_3 groups of triethyl amine, respectively [29]. According to the ^{1}H NMR measurements (Fig. S3), three singlet signals were observed at 8.3 ppm, 10.8 ppm, and 12.0 ppm, which can be assigned to the protons of CH=N, amine OH, and aldehyde O—H, respectively [9]. The presence of the azomethine proton confirms the formation of the ligand, while the protons of the aromatic rings are observed in the range of 7.2–8.1 ppm [2]. In title V(V) complex, the protons of the azomethin moiety and aromatic rings were spotted at 10.1 and 6.7–9.3 ppm respectivley. The triplet and quaternary peaks observed at 1.2 ppm and 3.1 ppm are assigned to the CH_3 and CH_2 groups of triethylamine [30]. In the UV–Vis spectrum of the $[H_2L]$ ligand (Fig. S4), three absorption bands appeared at 320 nm, 450 nm, and 470 nm can be attributed to $\pi \rightarrow \pi^*$ transition in the aromatic rings, $\pi \rightarrow \pi^*$ transition in the azomethine, and $n \rightarrow \pi^*$ transition in azomethine, respectively. In the case of the V(V) complex, the absorption band corresponded to the $\pi \rightarrow \pi^*$ transition is observed at 345 nm. The absorption peak appeared at 455 nm is related to the charge transfer from the ligand to the metal (LMCT) [2,6].

The title complex was used in the synthesis process of tetrahydro-4H-chromene derivatives in order to evaluate its catalytic activity. At first, an initial optimization was conducted on the reaction conditions (temperature, solvent, and catalyst loading). Three different solvents (DI water, acetonitrile, and ethanol), three different levels of catalyst loading (5, 10, and 20 mol%), and four levels of temperature (30, 50, 80, 100 °C) were used in this optimization. The title V(V) complex acted as a homogenous catalyst and finally column chromatography was used for the purification of the product. For a complete list of the results obtained from this optimization, one can refer to Tables S3–S5. As one can see, the di-oxido vanadium(V) complex shows an optimum catalytic performance (97% yield and the reaction time of 45 min) in acetonitrile at 50 °C, using 10 mol% catalyst loading for the synthesis of 2-amino-7,7-dimethyl-5-oxo-4-phenyl-5,6,7,8-tetrahydro-4H-chromene-3-carbonitrile (1a). Using the optimal conditions, various tetrahydro-4H-chromene derivatives were synthesized [29,31]. Table 1 reports the obtained reaction time and yield for the synthesis of tetrahydro-4H-chromenes using the aromatic aldehydes. According to the obtained results, the nature and position of the substituents on the aromatic ring have no discernible impact on the success of the reaction. In addition, the recyclability of the di-oxido vanadium(V) complex was studied by monitoring the efficiency of the catalyst after three consecutive runs under the optimal conditions (**1a**: 97%, 95%, 93%). The efficiency of the catalyst was reduced by only 4% after three consecutive runs, which demonstrated the ability of the catalyst for multiple uses.

In order to compare the performance of $[VO_2(L)](NHET_3)$ complex, the obtained results in this study were compared with those of the previously catalysts used in the catalytic synthesis of 1a. As can be seen in Table 2, the yield, reaction time, and temperature of the reaction are superior or comparable with the other catalysts [2,29,32–33]. The possible mechanism proposed for the synthesis of tetrahydro-4H-chromene derivatives catalyzed by the di-oxido-vanadium(V) complex is shown in Fig. 2.

The antibacterial activity of $[H_2L]$ and $[VO_2(L)](NHET_3)$ complex against *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Bacillus cereus* bacteria were evaluated using inhibition zone and MIC assays (Fig. 3). According to the obtained results (Table 3), $[H_2L]$ ligand is effective on all of the studied bacteria, except *E. coli*. However, the $[VO_2(L)](NHET_3)$ complex have higher antibacterial activity against both gram-negative and gram-positive bacteria, especially *Staphylococcus aureus*. Interestingly, this complex shows a considerable

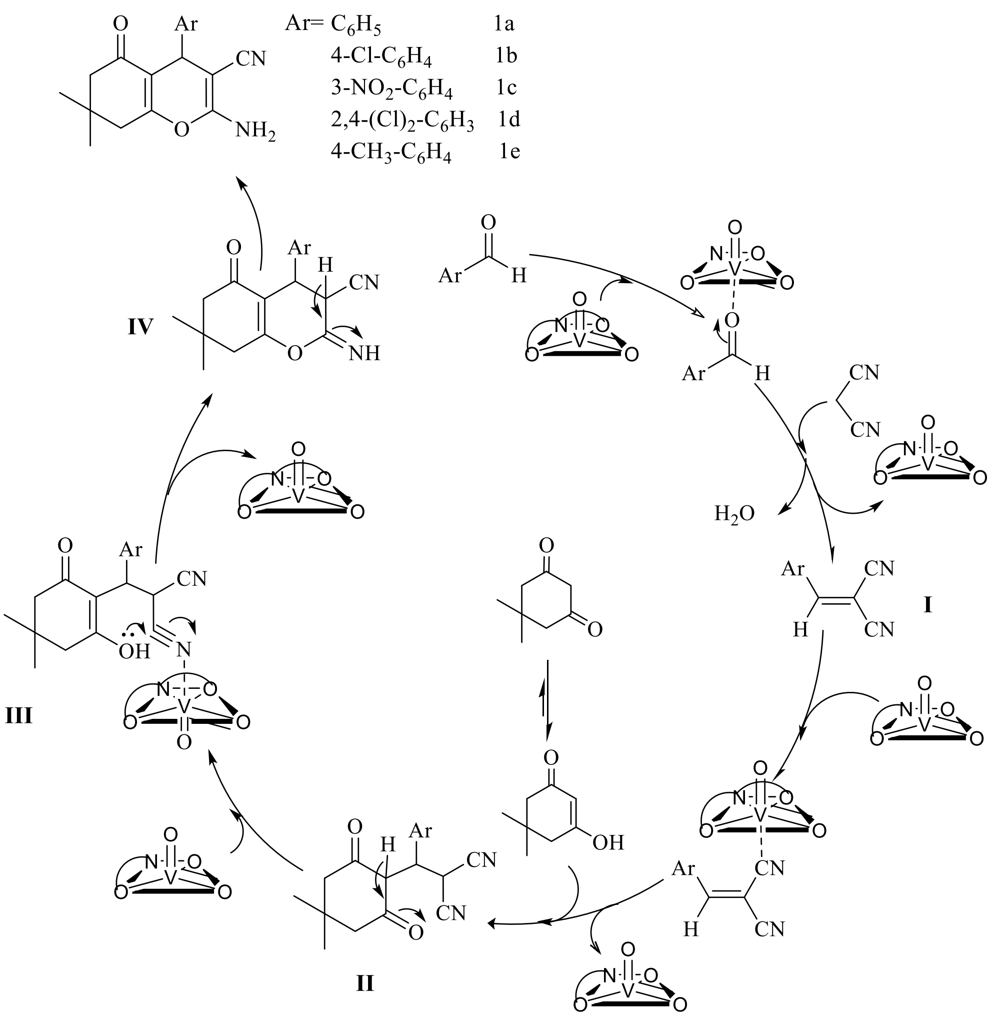


Fig. 2. Proposed mechanism for the synthesis of tetrahydro-4H-chromene derivatives catalyzed by di-oxido vanadium(V) complex.

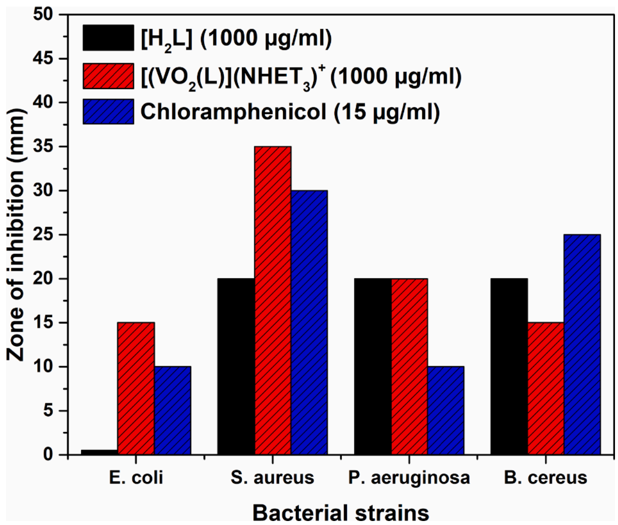


Fig. 3. The measured zone of inhibition (mm) of [H_2L] (1000 µg/ml), [VO_2(L)]($NHET_3$) (1000 µg/ml) and chloramphenicol antibiotic (15 µg/ml) as positive control against *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Bacillus cereus* bacteria.

Table 3
Antimicrobial activities of [H_2L] and [VO_2(L)]($NHET_3$)$^+$ complex against gram-positive and gram-negative bacteria determined by the inhibition zone method.

	[H_2L]		[VO_2(L)] ($NHET_3$)		Positive control
	500 µg/ml	1000 µg/ml	500 µg/ml	1000 µg/ml	(Chloramphenicol 15 µg/ml)
Escherichia coli	0	0	25	15	10
Staphylococcus aureus	20	20	35	35	30
Pseudomonas aeruginosa	10	20	15	20	10
Bacillus cereus	10	20	25	15	25

Table 4
The MIC values (µg/ml) of [H_2L] and [VO_2(L)]($NHET_3$) complex against studied microorganisms.

	E. coli	*S. aureus*	*P. aeruginosa*	*B. cereus*
[H_2L]	250	7.8	250	31.2
[VO_2(L)]($NHET_3$)	250	250	125	125

antibacterial activity against *E. coli*, even though this bacteria is resistant to the parent ligand. The obtained MIC values for [H_2L] and [VO_2(L)]($NHET_3$) complex are reported in Table 4, and it can be inferred that the antibacterial activity of $[VO_2(L)](NHET_3)$ complex against *P. aeruginosa* bacteria is considerably higher (125 μg/ml) than that of $[H_2L]$ (250 μg/ml).

Based on the previous studies [6,30], the enhanced activity of $[VO_2(L)](NHET_3)$ complex against microorganisms can be attributed to the delocalization of the π-electrons in chelate moiety and also the positive charge of the central atom in the complex. The two mentioned phenomena have a significant impact on the lipophilicity of the complex, which will facilitate its penetration into the microorganism membranes and, eventually result in the cell death.

In conclusion, a tridentate ONO Schiff base ligand;1-[(((2 hydroxyphenyl)imino)methyl)]naphthalen-2-ol $[H_2L]$ and its di-oxido vanadium(V) complex $[VO_2(L)](NHET_3)$ were successfully synthesized and fully charecterized. The di-oxido vanadium(V) complex showed enhanced antibacterial activity against all of the studied microorganisms (especially *Staphylococcus aureus*), which confirmed the antibacterial activity of the synthesized complex. The efficiency of the $[VO_2(L)](NHET_3)$ complex as the catalyst remains more than 90% even after three consecutive runs. High yield, mild temperature reaction, and the possibility to use the $[VO_2(L)](NHET_3)$ catalyst several times are the advantages of the synthesized complex in comparison to the previously reported catalysts for the synthesis of tetrahydro-4H-chromene derivatives.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors gratefully acknowledge the financial support provided for this work by the Shahid Bahonar University of Kerman.We would like to specially thank samia benmansour from Universidad de Valencia for helping us in crysatlography section.

Appendix A. Supplementary material

The synthesis and characterization of the ligand $[H_2L]$ and its di-oxido vanadium(V) complex, Crystal structure determination, Catalytic activity, Parameters optimization, Biological activity and related figures and tables are in Supporting information. Crystallographic data for the structure reported in this paper have been deposited with the Cambridge Crystallographic Data Centre, CCDC No. 2033464. Copies of this information may be obtained from the Director, CCDC, 12 Union Road, Cambridge, CB2 1EZ, UK (fax: +44-1223-336033; e-mail: deposit@ccdc.cam.ac.uk or http://www.ccdc.cam.ac.uk). Supplementary data to this article can be found online at https://doi.org/10.1016/j.inoche.2021.108561.

References

[1] M. Mohamadi, A. Rezaei, S.Y. Ebrahimipour, S.K. Falahati-pour, F. Mohamadizadeh, M. Bemani, M.R. Hajizadeh, M.R. Mirzaei, A. Khoshdel, M. Mahmoodi, In-silico and in-vitro studies on the DNA/BSA-binding features of a mixed ligand copper (II) complex containing 2-methyl imidazole and a schiff base ligand, ChemistrySelect 4 (2019) 13932–13939.

[2] S.Y. Ebrahimipour, M. Khosravan, J. Castro, F.K. Nejad, M. Dusek, V. Eigner, Synthesis and structure elucidation of a novel mixed-ligand Cu (II) Schiff base complex and its catalytic performance for the synthesis of 2-amino-4H-pyrans and tetrahydro-4H-chromenes, Polyhedron 146 (2018) 73–80.

[3] X. Liu, J.-R. Hamon, Recent developments in penta-, hexa-and heptadentate Schiff base ligands and their metal complexes, Coord. Chem. Rev. 389 (2019) 94–118.

[4] S. Chen, X. Liu, X. Ge, Q. Wang, Y. Xie, Y. Hao, Y. Zhang, L. Zhang, W. Shang, Z. Liu, Lysosome-targeted iridium (III) compounds with pyridine-triphenylamine Schiff base ligands: syntheses, antitumor applications and mechanisms, Inorg. Chem. Front. 7 (2020) 91–100.

[5] W. Al Zoubi, A.A.S. Al-Hamdani, M. Kaseem, Synthesis and antioxidant activities of Schiff bases and their complexes: a review, Appl. Organomet. Chem. 30 (2016) 810–817.

[6] S.Y. Ebrahimipour, M. Khosravan, J. White, S. Fekri, Preparation, crystal structure, spectroscopic studies, DFT calculations, antibacterial activities and molecular docking of a tridentate Schiff base ligand and its cis-MoO2 complex, Appl. Organomet. Chem. 32 (2018) e4233.

[7] F. Khajoee Nejad, M. Khosravan, S.Y. Ebrahimipour, F. Bisceglie, A mixed-ligand quinazoline-based Ni (II) Schiff base complex: Synthesis, characterization, crystal structure, antimicrobial investigation and catalytic activity for the synthesis of 2H–indazolo [2,1-b] phthalazine-triones, Appl. Organomet. Chem. 32 (2018).

[8] N. Lotfi, I. Sheikhshoaei, S.Y. Ebrahimipour, H. Krautscheid, Synthesis, characterization, crystal structure, and DFT studies of a cis dioxo-vanadium (V) complex containing a tridentate (NNO) Schiff base ligand, J. Mol. Struct. 1149 (2017) 432–438.

[9] S.Y. Ebrahimipour, B. Machura, M. Mohamadi, M. Khaleghi, A novel cationic cobalt (III) Schiff base complex: Preparation, crystal structure, Hirshfeld surface analysis, antimicrobial activities and molecular docking, Microbial Pathogenesis 113 (2017) 160–167.

[10] M. Mohamadi, S.Y. Ebrahimipour, J. Castro, M. Torkzadeh-Mahani, Synthesis, characterization, crystal structure, DNA and BSA binding, molecular docking and in vitro anticancer activities of a mononuclear dioxido-uranium (VI) complex derived from a tridentate ONO aroylhydrazone, J. Photochem. Photobiol., B 158 (2016) 219–227.

[11] M. Pervaiz, I. Ahmad, M. Yousaf, S. Kirn, A. Munawar, Z. Saeed, A. Adnan, T. Gulzar, T. Kamal, A. Ahmad, Synthesis, spectral and antimicrobial studies of amino acid derivative Schiff base metal (Co, Mn, Cu, and Cd) complexes, Spectrochim. Acta Part A Mol. Biomol. Spectrosc. 206 (2019) 642–649.

[12] R. Bikas, P. Mirzakhani, N. Noshiranzadeh, J. Sanchiz, M.S. Krawczyk, D. A. Kalofolias, T. Lis, Synthesis, crystal structure and magnetic properties of a pentanuclear Mn (III) cluster with 1, 2, 4-triazole based Schiff base ligand, Inorg. Chim. Acta 505 (2020) 119461.

[13] M.K. Ghosh, S. Pathak, T.K. Ghorai, Synthesis of two mononuclear schiff base metal (M= Fe, Cu) complexes: MOF structure, dye degradation, H2O2 sensing, and DNA binding property, ACS Omega 4 (2019) 16068–16079.

[14] H.F.G. Barbosa, É.T.G. Cavalheiro, The influence of reaction parameters on complexation of Zn (II) complexes with biopolymeric Schiff bases prepared from chitosan and salicylaldehyde, Int. J. Biol. Macromol. 121 (2019) 1179–1185.

[15] Z. Saedi, E. Hoveizi, M. Roushani, S. Massahi, M. Hadian, K. Salehi, Synthesis, characterization, anticancer properties and theoretical study of asymmetrical Cd (II) N2-Schiff base complexes, J. Mol. Struct. 1176 (2019) 207–216.

[16] M. Sankarganesh, J.D. Raja, N. Revathi, R.V. Solomon, R.S. Kumar, Gold (III) complex from pyrimidine and morpholine analogue Schiff base ligand: synthesis, characterization, DFT, TDDFT, catalytic, anticancer, molecular modeling with DNA and BSA and DNA binding studies, J. Mol. Liq. 294 (2019) 111655.

[17] T. Baran, Highly recoverable, reusable, cost-effective, and Schiff base functionalized pectin supported Pd (II) catalyst for microwave-accelerated Suzuki cross-coupling reactions, Int. J. Biol. Macromol. 127 (2019) 232–239.

[18] F. Heidari, S.J.A. Fatemi, S.Y. Ebrahimipour, H. Ebrahimnejad, J. Castro, M. Dušek, V. Eigner, Six-coordinate oxo-vanadium (V) dimer complex with methoxy bridging: Synthesis, crystal structure, biological activity and molecular docking, Inorg. Chem. Commun. 76 (2017) 1–4.

[19] D.C. Crans, J.T. Koehn, S.M. Petry, C.M. Glover, A. Wijetunga, R. Kaur, A. Levina, P.A. Lay, Hydrophobicity may enhance membrane affinity and anti-cancer effects of Schiff base vanadium (V) catecholate complexes, Dalton Trans. 48 (2019) 6383–6395.

[20] H.M. Hassan, M.A. Betiha, E. El-Sharkawy, R.F. Elshaarawy, N. El-Assy, A. A. Essawy, A. Tolba, A.M. Rabie, Highly selective epoxidation of olefins using vanadium (IV) schiff base-amine-tagged graphene oxide composite, Colloids Surf., A 591 (2020) 124520.

[21] M. Bagherzadeh, M. Bahjati, A. Mortazavi-Manesh, Synthesis, characterization and catalytic activity of supported vanadium Schiff base complex as a magnetically recoverable nanocatalyst in epoxidation of alkenes and oxidation of sulfides, J. Organomet. Chem. 897 (2019) 200–206.

[22] X. Wang, X. Zhang, P. Li, K.-I. Otake, Y. Cui, J. Lyu, M.D. Krzyaniak, Y. Zhang, Z. Li, J. Liu, Vanadium catalyst on isostructural transition metal, lanthanide, and actinide based metal–organic frameworks for alcohol oxidation, J. Am. Chem. Soc. 141 (2019) 8306–8314.

[23] Q. Zhao, N. Katyal, I.D. Seymour, G. Henkelman, T. Ma, Vanadium (III) acetylacetonate as an efficient soluble catalyst for lithium–oxygen batteries, Angew. Chem. 131 (2019) 12683–12687.

[24] P.K. Gupta, S. Vaswani, V. Kumar, D. Roy, M. Kumar, R. Kushwaha, A. Kumar, A. Shukla, Investigations on modulating effect of vanadium supplementation on growth and metabolism through improved immune response, antioxidative profile and endocrine variables in hariana heifers, Biol. Trace Element Res. 194 (2020) 379–389.

[25] S. Kowalski, D. Wyrzykowski, I. Inkielewicz-Stępniak, Molecular and cellular mechanisms of cytotoxic activity of vanadium compounds against cancer cells, Molecules 25 (2020) 1757.

[26] D. Hu, D. Li, X. Liu, Z. Zhou, J. Tang, Y. Shen, Vanadium-based nanomaterials for cancer diagnosis and treatment, Biomed. Mater. 16 (2020) 014101.

[27] M. Skyllas-Kazacos, L. Cao, M. Kazacos, N. Kausar, A. Mousa, Vanadium electrolyte studies for the vanadium redox battery—a review, ChemSusChem 9 (2016) 1521–1543.

[28] A. Addison, T. Rao, J. Reedijk, J. van Rijn, G. Verschoor, Spectroscopic Properties of Copper (II) Compounds Containing Nitrogen-Sulphur Donor Ligands; the Crystal

and Molecular Structure of Aqua [1, 7-bis (N-Methylbenzimidazol-2′-yl)-2, 6-Dithiaheptane] Copper (II) Perchlorate, J. Chem. Soc. Dalton Trans 7 (1984) 1349–1356.

[29] M. Abaszadeh, M. Seifi, S.Y. Ebrahimipour, Two ligand oxidio-vanadium (IV) complexes as novel efficient catalysts in multicomponent reactions for synthesis of tetrahydrobenzopyran derivatives, Bull. Chem. Soc. Ethiop. 30 (2016) 253–262.

[30] S.Y. Ebrahimipour, I. Sheikhshoaie, J. Simpson, H. Ebrahimnejad, M. Dusek, N. Kharazmi, V. Eigner, Antimicrobial activity of aroylhydrazone-based oxido vanadium (v) complexes: in vitro and in silico studies, New J. Chem. 40 (2016) 2401–2412.

[31] Z. Zhou, F. Yang, L. Wu, A. Zhang, Potassium phosphate tribasic trihydrate as catalyst for the rapid and clean one-pot synthesis of 2-amino-4H-chromenes under solvent-free conditions, Chem. Sci. Trans. 1 (2012) 57–60.

[32] A. Boumoud, A. Yahiaoui, T. Boumoud, A. Debache, A Novel Catalyst for One-pot Synthesis of Tetrahydrobenzo [b] pyran derivatives, J. Chem. Pharm. Res 4 (2012) 795–799.

[33] T.-S. Jin, J.-C. Xiao, S.-J. Wang, T.-S. Li, X.-R. Song, An efficient and convenient approach to the synthesis of benzopyrans by a three-component coupling of one-pot reaction, Synlett 2003 (2003) 2001–2004.