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Oxovanadium Chemistry: A Concise Overview of its Compounds and their Applications

Kamal Prasad Sapkota[1], Bharat Prasad Sharma[1,2,] and M. L. Sharma[1]*

Abstract

Multi-drug resistivity and promptly mutating pathogenicity in micro-organisms as well as the emergence of adverse effects of the antibiotics have urged for the quest of novel versatile compounds derived from synthesized compounds. Moreover, the scientific world is in search of a synthetic species that demonstrate significant anti-diabetic and insulin-mimic impacts through improved glucose conveyance and inhibition of lipolysis metabolism, protein catabolism, and stimulation of glycogen production together with lipogenesis in skeletal muscle, adipocytes, and hepatocytes. Accordingly, in the quest for a panacea against several such health-related and environmental problems, the explorations in oxovanadium complexes have been given due credit in this review. Based on the in-depth research and findings of the researchers, oxo-vanadium complexes have been highlighted as versatile materials to be used as antimicrobial, anticancer, antifungal, antidiabetic, and catalytic agents. The review also incorporates the future challenges and prospects of the oxovanadium complexes.

Keywords: Oxovanadium, Panchromium, Vanadium, Ferrovanadium, Anticarcinogenic

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1 Central Department of Chemistry, Institute of Science and Technology, Tribhuvan University, Kirtipur, Kathmandu 44600, Nepal.

2 College of Material Science and Engineering, Beijing University of Chemical Technology, Beijing 100029, P.R. China

* *Corresponding author: mlsharma.tu@gmail.com*

Introduction

Vanadium is a steel-grey colored metal with corrosion-resistive properties, revealed in 1801 by the Spanish mineralogist Andres Manuel del Rio during the investigation of "brown lead," a naturally occurring ore found in Mexico. He gave the name "Panchromium" to this element due to its ability to change color during its transition to various oxidation states. Later, in 1831, Nils Gabriel Sefstrom rediscovered vanadium while studying the brittleness of steel and gave the name vanadium inspired by the Nordic goddess Vanadis because of the beautiful compounds formed by vanadium (Rohrmann, 1958). Vanadium($_{23}$V) is located as the first element of group 5 of the modern periodic table with the electronic configuration [Ar] $3d^3$ $4s^2$. Its atomic mass is 50.9 g/mol and its density is 6.11 g/cm^3. It has several desirable characteristics such as moderate hardness, ductility, and an exceptionally high melting point of 1929 °C. Vanadium is more difficult to work with than most metals and steel, as it resists alkalis, sulfuric, and hydrochloric acids and has good corrosion resistance (Eriksen *et al.*, 1995). Its peculiar characteristics are that it is electrically conductive but thermally insulating. It occurs in two isotopic forms; ^{50}V and ^{51}V (99.76%) of which the naturally occurring vanadium ^{50}V form having 0.24% abundance is faintly radioactive having a half-life of greater than 3.9×10^{17} years than ^{51}V which has 99.76% natural abundance (Bauer *et al.,* 2000). Vanadium ranks as the fifth most abundant transition element and the nineteenth position by weight among the elements in the Earth's crust, predominantly found in ores and alloys. It is not only found in its elemental state in nature but is also present in over sixty-five different minerals.

Vanadium sustains in a wide range of oxidation states, from -I to +V, making it chemically adaptable and valuable in various applications (Barceloux & Barceloux, 1999). It holds a unique position among bio-metals because of its ability to exist in both negative and positive states, enabling it to contribute to various biological mechanisms. When vanadium is in its anionic form, specifically as vanadate(V), it resembles phosphates to some extent. This similarity is due to the comparable chemical behavior and structure of vanadate(V) and phosphates. In its cationic form, especially as VO^{+2} and occasionally as VO^{3+}, vanadium acts like a distinctive transition metal ion. In this state, vanadium has a stronger capacity than other transition metals for coordination with biologically active ligands to form compounds (Baran, 2000). Natural vanadium and its compounds display vivid colors, assigned to the d-d electronic transitions. However, color can also arise from defects within the solids or through charge transfer spectra. In the case of vanadium(IV), the color arises from electron transition from the $2t_{2g}$ to the $2e_g$ state in octahedral complexes (Nayak *et al.*, 2022). These complexes comprise the d^1 electronic structure where vanadium(IV) exhibits a coordination sphere and possesses a highly distorted square pyramid, which is commonly observed in other similar compounds. The coordination involves two imine nitrogen, two oxygen of phenol moiety derived from ligands, and a vanadyl oxo atom (Barfeie *et al.*, 2018). Sharma *et al.* reported that oxovanadium(IV) complexes normally have bipyramidal or square pyramidal structures corresponding to the oxygen bonded with vanadium with a distance of 0.035-0.055 Å above the plane than the plane of ligands (Sharma *et al.*, 2012).

Many metal ions have shown a key role in living organisms. Many kinds of cereal, fish, fresh fruit, mushrooms, and some sea animals have the presence of vanadium compounds. Although vanadium is normally present in lower concentrations ($> 10^{-8}$ M), it plays a significant role in both plant and animal cells (Rehder, 1991). However, it is found in extremely high concentrations in some oceanic ascidian, some mushrooms, and some worms (Baran, 2000). Vanadium has biological importance because of its ability to get involved in numerous physiological processes (Fedorova *et al.*, 2014). This element influences some metabolic events like the metabolism of nitrogen, biosynthesis of chlorophyll, and modulation of the regulatory enzyme through activation and inhibition (Meisch & Bieling, 1980).

Previously, vanadium was believed to be slightly toxic and carcinogenic. However, vanadium is now approved as a vital trace element having antibiotic and anticarcinogenic behavior (Mukherjee *et al.*, 2004). The diverse pharmacological activity of vanadium compounds demonstrates their efficacy in treating parasitic infections, malignant cancers, and other pathogenic infections. Numerous medicines based on vanadium have been investigated, offering promising options for therapeutic interventions. The use of inorganic vanadium gained attention in the early cure of diabetes mellitus; nowadays organic vanadium compounds are increasingly attracting attention. Vanadium chemistry is gaining more and more importance day by day due to its biological and commercial applications, including its antimicrobial to anticancer and more recently, insulin-mimetic capabilities (Charistos *et al.*, 2001).

Findings

Chemistry of Vanadium in Brief

Vanadium is a member of the transition element family, Group 5 (along with Tantalum, Niobium, Protactinium, etc) of the periodic table. It exhibits a range of oxidation from (-III) to (+V) except (-II). In contrast to other metals, vanadium has a high number of stable oxidation states (+II, +III, +IV, +V); each of which is characterized by unique color in solution. However, (+IV) and (+V) are the most stable states (Krakowiak *et al.*, 2012). Meanwhile, the vanadium is readily contaminated by several other elements; therefore, the yielding of pure vanadium is difficult. Processes like calcium reduction, thermal decomposition, solvent extraction, and electrolytic refining are the common methods employed to manufacture refined metal (Moskalyk & Alfantazi, 2003).

Vanadium is recognized as a trace element which is found naturally around 0.02% only and extremely important vanadium comes in both organic and inorganic forms. Among them, the organic forms of vanadium exhibit a greater therapeutic effect than the inorganic forms and are safer to handle (Badmaev *et al.*, 1999). Vanadium is likely a crucial metal and the oxovanadium ion is recognized as the effective inhibitor for the Na/K AT-Pase Pump. According to a study, vanadium assists in controlling the Na pump (Imtiaz *et al.*, 2015).

Common vanadium-containing ores include roscoelite, vanadinite, patronite (impure vanadium sulfide), vannotite (potassium uranyl vanadate), and phosphate rock (Selbin, 1996). These ores can be extracted by thermal decomposition, solvent extraction, electrolytic refinement, and calcium reduction. Some of these ores may be extracted to create alloys high in vanadium, such as ferrovanadium (International Programme on Chemical Safety, UNEP, 1988). Vanadium is used to make steel and non-ferrous alloys, as a catalyst in the manufacture of H_2SO_4, and to change naphthalene into phthalic anhydride while making plastic, as a colorant in semiconductors, photo-graphic developers, and ceramics, and for the production of yellow pigments and ceramics.

The latest development in the catalytic and therapeutic potential of vanadium complexes have motivated their designing, synthesis, and prospective bioactive applications in drug chemistry (Sharma *et a*l., 2012). The proper accustoming of vanadium compounds with chelated chemical ligands has improved bioavailability, hydrolytic stability, and hydrophilicity. When exposed to water, vanadium complexes are prone to hydrolysis and produce several compounds. Consequently, efforts are still being made to stabilize vanadium complexes with organic ligands (Reytman *et al*., 2018).

Vanadium and its compounds are colorful. The *d-d* electronic transitions are responsible for a particular color in vanadium compounds (Sharma et al., 2023). However, it may be also caused by defects in the solid state and charge transfer spectra. The color of vanadium(IV) comes from the transition of an electron from the $^2T_{2g}$ to the ^2E_g state in octahedral complexes, which have a d^1 electronic structure. A spectral diagram is demonstrated in **Figure 1** (Lee, 2010).

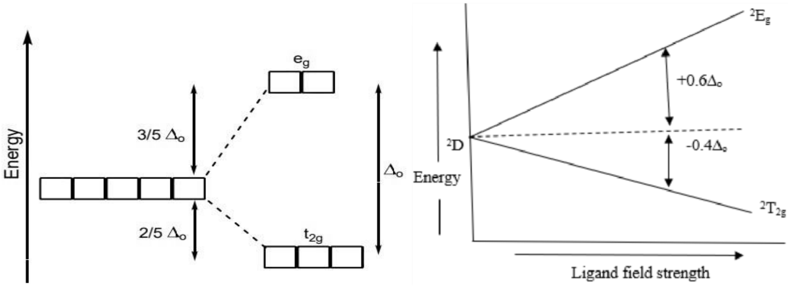


Figure 1: Energy level splitting diagram for d^1 configuration in an octahedral field (Lee, 2010)

The VO^{2+} ion, also known as oxovanadium (IV) ion or vanadyl ion, is a common ion of vanadium (IV) complexes. It can make different stable compounds having a variety of charges with various types of Schiff bases (Bhava *et.al.*, 2013). Vanadium acts as a cofactor in vanadium-dependent haloperoxidase, nitrogenase, oxygenase, phosphatase, insulin-mimetic, etc.

(Barfeie *et al.*, 2018) and is being studied for use in electrochemical storing like in battery technology vanadium-redox-flow-batteries (VRFB), that could be commercialized in the feature.

Vanadium Complexes

The coordination chemistry of vanadium with Schiff base ligands pertinent to biological systems is at the forefront of research (Crans *et al.*, 2004). The development of organic vanadium complexes represents a significant step in the utilization of vanadium (Majithiya *et al.*, 2005). For the treatment of obesity and hypertension, a number of vanadium compounds of the Salen-type multidentate Schiff bases chelates have been recommended. In 1985, John McNeill initiated a new direction of research into the diabetic cure capability of vanadium by monitoring the cardiac utility of rats treated with vanadyl sulfate for streptozotocin-induced diabetes. Since then, numerous biological activity research has been investigated to determine the effects of animal models and *in vitro* tests for induced diabetes using inorganic and organic vanadium compounds. The publication of two monographs demonstrates the rise in interest in the biological properties of vanadium chelates during the 1990s (Pessoa *et al.*, 2015; Rehder, 1991). Numerous industries, including the catalytic industry, bioinorganic chemistry, electrochemistry, and molecular-based magnetism, have found usage for the oxovanadium(IV) complexes (Matsuoka *et al.*, 2011).

Recently, it has been proven that several Schiff bases synthesized from coumarins and sulfonamides, as well as their complexes with metals, are slightly carcinogenic and the reduction in cytotoxicity has been achieved through coordination with metal ions (Sharma *et al.*, 2012). The vanadium compounds with a +4 oxidation state are usually more significant among many compounds than other different oxidation states.

Oxovanadium(IV) Complexes

Oxovanadium (IV) complexes exhibit different coordination geometries; square pyramidal, octahedral, and trigonal bipyramidal structures, with the vanadyl oxygen acting as the apical ligand. The chemistry of oxovanadium(IV) has been extensively studied due to the ability of the VO^{+2} unit to bind with 4, 5, or 6 coordinating atoms, forming VOL_4, VOL_5, and VOL_6 type complexes, respectively (**Figure 2**). The highly stable oxovanadium(IV) ion reveals a notable occurrence in various states (solid, liquid, and vapor) forming numerous stable complexes that can be cationic, anionic, or neutral (Sharma *et al.*, 2023). Vanadium in VO^{+2} complexes typically exists in three common geometrics, namely the square pyramidal, distorted octahedral, and the trigonal bipyramidal. In square pyramidal complexes, the distance between vanadium and oxygen is approximately 1.6 Å (Garribba *et al.*, 2003).

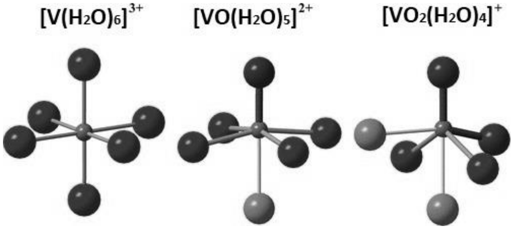
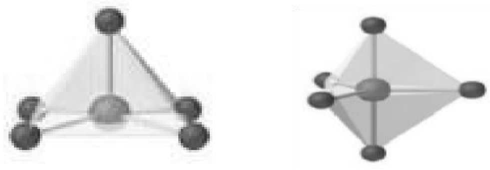


Figure 2: Coordination of the V(III), VO(IV), and VO(V) with the donor atoms in different geometries (Krakowiak *et al.,* 2012).

The square pyramidal or octahedral geometry was recognized with the oxovanadium (IV) with the apical position of oxygen and the equatorial coordination of ligands with the vanadium atom lying slightly above the plane of ligands. The five coordinated trigonal bipyramidal and square pyramidal complexes are determined by X-ray technique (Garribba *et al.*, 2003), which are shown in **Figure 3.**



(I) (II)

Figure 3: Square pyramidal (I), and trigonal bipyramidal (II) structures.

When the oxygen attached to the vanadium of a molecule coordinates with a vanadium atom from a nearby molecule's open axial site, an endless −V=O−V=O− polymeric form is created in oxovanadium. The valance orbitals with one and two elections determine how the mechanism of spin polarization occurs in the oxovanadium species. The beginning of larger spin extent in the vanadyl oxygen in the 2*p* orbital is due to the lapping of the $3dz^2$ orbital for the sigma bonding whereas $3d_{zx}$ and $3d_{yz}$ orbitals for the pi bonding (Matsuoka *et al.*, 2011). The appearance of the V=O group on the tetragonal state, the oxovanadium(IV) complexes exhibit three allowed transitions, namely $d_{xy} \rightarrow dz^2$, $d_{xy} \rightarrow d_{zx}$, d_{yz}, and $d_{xz} \rightarrow d_x^2\text{-}d_y^2$ (Matsuoka *et al.*, 2011).

Schiff Bases and their Compounds with Oxovanadium

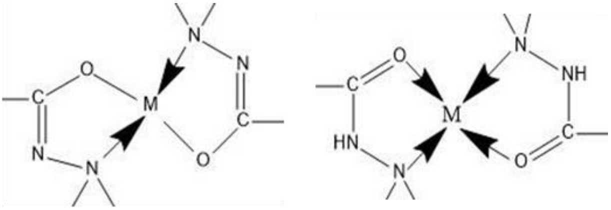
A German chemist Hugo Schiff discovered Schiff Bases (SBs) and the Schiff test, which he named after himself. Schiff bases are formed by the reaction of primary amines with carbonyl compounds, resulting in the formation of a >C=N double bond (Sharma *et al.*, 2023). The imines formed (R'R"C=N–R or R'HC=N–R) interact with metal ions through a dative bond due to the lone pair electrons present in the imine group. The formation of SBs is easier in case of aldehydes than in ketones. The disadvantage associated with SBs is that if there is no any aromatic moiety connected to nitrogen or carbon of the imine (C=N) bond, SBs decompose or polymerize quickly (Sharma *et al.*, 2021). As a result, SBs with aryl groups are significantly highly stable and easier to prepare, whereas those with alkyl groups are comparatively less stable whereas with aliphatic aldehydes are more likely unstable and easily polymerize (Nazeer, 2017) and those with aromatic aldehydic substituents with more conjugation are comparatively stable (Sharma et al., 2022).

Scheme 1: Formation of Schiff Base

Schiff base complexes can offer synthetic routes for the metal-based compounds in metalloproteins as well as contribute to medicinal chemistry developments. Hence, SBs and their complexes have a wide range of applications in biology, medicine, and chemistry (Sharma *et al.*, 2021). Metal complexes with SBs have piqued the interest of researchers due to their antifungal (Lima *et al.*, 2021), antitumor, and antibacterial properties (Sharma *et al.*, 2021). In +3, +4, and +5 oxidation states, vanadium can comfortably bind N and S to form complexes. This versatility is the reason for vanadium complexes possessing unique properties (Sharma *et al.*, 2012). Imines, or Schiff base ligands, are one of the most extensively used organic ligands in the field of the coordination chemistry of transition metals. In recent years, the chelating chemistry of the complexes of Schiff bases with oxovanadium(IV) and dioxidovanadium(V) with nitrogen, oxygen, and sulfur-donor chelates are drawing significant attention due to their remarkable structural frameworks, bioactive and medicinal effectiveness as insulin-mimetic profile, anti-parasitic and anti-tumor activities and spermicidal (Dekar *et al.*, 2018). Moreover, they are believed to act as co-factors for enzymes that participated in blood-sugar stabilization mechanism, lipid and cholesterol related metabolic functions, growth metabolism of bone and tooth, fertility metabolism, thyroid metabolism, hormonal function, and neurotransmitter functions (Charistos *et al.*, 2001).

1,2,4-Triazole derivatives demonstrate a variety of interesting biological activities which include antibacterial, antiproliferative, anticonvulsant, antitubercular, cytotoxic, analgesic, and plant growth regulatory (Sahani *et al.*, 2014). These compounds contain heterocyclic groups. The 1,2,4-triazole compounds containing amino groups are used to produce Schiff bases with well-known medicinal properties (Barfeie *et al.*, 2018). Thus, it can be inferred that the biological activeness of such compounds as drugs is enhanced upon coordination with metal ions like vanadium (Sharma *et al.*, 2021). Thus, in the last decades, chemists and biochemists have been attracted to the production of a new class of 1,2,4-triazole Schiff bases and their compounds with oxovanadium(IV) ion.

It exhibits a wide range of biological activities due to the presence of bond and lone pair electrons on the nitrogen atoms. The benefit of hydrazone Schiff bases as ligands lies not only in their ease of synthesis, which yields a wide range of donor atoms (mostly O, N, but also S and others) but also in their versatility during coordination and protonation/deprotonation, which adapts to the metal oxidation state and yields a neutral complex (Aboafia *et al.*, 2018). Hydrazide ligands and hydrazone compounds have many chelating sites and can bind to coordinating metal ions in the enol (I) as well as keto (II) forms as displayed in **Figure 4**. Through nitrogen and/or oxygen, ligands with an amide moiety and due to the keto-enol tautomerism can coordinate with metal atoms and the nature of coordination varies with the pH of the system, the structure of the ligand, and the property of the metal ions. Hydrazones are a group of compounds with a wide spectrum of biological activity, including antifungal, antitumor, antiviral, anti-inflammatory, and antiplatelet assets (Maurya *et al.*, 2006), and antituberculosis activities (Pessoa *et al.*, 2015). Aroyl hydrazones and their metal derivatives are commonly used as pesticides and plant growth regulators, as well as in the treatment of various diseases.



(I) (II)

Figure 4: Structure of enolic (I) and ketonic (II) form of hydrazine metal complexes (Gamil, Ahmed, & A 2009)

The Schiff bases can be directly synthesized, and the ease of their variation makes them quite interesting in coordination chemistry and are prepared by using a routine synthetic procedure with the combination of an amine with a carbonyl compound. Schiff base acts as a ligand in coordination chemistry (Kollur *et al.*, 2018; Santra *et al.*, 2022). Several types of complexes of Schiff bases are examined for their biochemical and medicinal application and found to be potent and function as drugs (Vinusha *et al.*, 2019; Zoubi, 2013).

Schiff bases include an amine that is comparable to the amine found in biological systems in nature, they are useful for examining the adaptation process and racemization process in living beings (Andiappan *et al.*, 2018). Coordination complexes of Schiff bases have found application in different research fields, like the capacity to reversibly combine oxygen, the catalytic property during the hydrogenation of olefin, their photochromic qualities, and their ability to bind with some toxic metals. Several biologically noteworthy Schiff base ligands with antibacterial, antifungal, antiviral, antitumor, anti-tuberculosis properties, etc. have been reported in the literature (Mapari, 2017).

Characterization of the Complexes

The confirmation of the synthesis of metal complexes can be confirmed through the use of different characterization techniques. Prominent characterization techniques are introduced in this section.

Fourier transform infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FTIR) is a most beneficial technique for verifying the characteristics of pure compounds. The method is based on recognizing functional groups within the molecules that vibrate (either by stretching or by bending in different states) when exposed to particular wavelengths of IR radiation. However, its utility is limited if it is applied to compound mixtures. The advantage of FTIR is that the method is non-destructive and does not necessitate derivatization.

Ultraviolet-visible (UV–vis) spectroscopy

UV–vis spectroscopy is also a most significant method that can be used to identify pure compounds. Generally, UV and UV–vis spectroscopy have been performed as the variation of absorbance as a function of wavelength, and the results are compared with the known standard samples. UV–vis is a cheap and viable technique for recording data with small portions of samples and discriminating pure compounds without requiring the need for derivatization. It is less useful for street samples containing a complex mixture.

X-ray diffraction (XRD)

X-rays are radiations with extremely high energy and electromagnetic waves with wavelengths varying from 10^{-3} to 10^{1} nm. XRD technique is based on the crystal’s ability to diffract radiations in a specific way, allowing for an accurate investigation of the structural behavior of solid phases. The peak intensity can be used to obtain information regarding crystalline morphology (atomic arrangements, temperature influence, or occupancy), including consistency and crystallinity assessments. Ultimately, the peak appearance provides details regarding sample widening contributions (micro strains and crystallite size) (Dinnebier & Billinge, 2008).

Applications of Oxovanadium Complexes

Oxovanadium(IV) complexes are well-known for their applications in diverse fields. Their applications can be studied under two major headings: biological applications and catalytic applications.

Biological importance

Oxovanadium(IV) metal complexes have gained remarkable attention because of their significant biological and industrial applications. These compounds have shown a broad range of medicinal effects incorporating antibacterial, antifungal, antiviral, anticancer, and insulin-mimetic activities (Sharma *et al.*, 2023).

Antibacterial properties

Antimicrobial testing has applications in drug discovery, epidemiology, and therapeutic outcome prediction. At present, effective antibiotics are in danger of dropping their effectiveness due to an increase in infectious resistance (Baran, 2000). Since many cases of treatment failures caused by multidrug-resistant bacteria have been reported worldwide, the synthesis of powerful alternatives has come to be a universal public health concern. Consequently, the discovery of new drugs is an extremely important goal.

To examine the efficacy of an agent's antimicrobial result, the time-kill tests and flow cytofluorometric methods are used, as they grant evidence on the characteristics of the inhibitory impact and the cell destruction imposed on the tested organisms. Because of the increased interest in the assets of new antimicrobial reagents, such as for fighting multidrug-resistant microbes, it is essential to have a better awareness of the existing screening approaches and/or quantify the antimicrobial outcome of a genuine compound for implication in human health, cultivation, and the atmosphere (Catalano *et al.*, 2022). The emergence of drug resistance and the arrival of disadvantageous effects of some antibiotic drugs have urged the exploration of new antimicrobial reagents derived from synthesized compounds (Baran, 2000).

Oxovanadium(IV) complexes synthesized from Schiff bases have been reported to have effective antimicrobial properties on several bacteria such as *Staphylococcus aureus, Escherichia coli*, *Klebsiella pneumonia,* etc. Moreover, it was found that coordination increased the antibacterial performance of simple ligands. Due to the higher concentration of nitrogen atoms in this coordination, it is considered to be a more powerful antibacterial agent (Rajavel *et al.*, 2008).

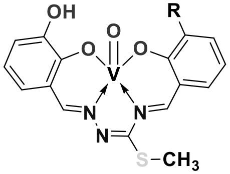


Figure 5: Oxovanadium complex having potential antibacterial activity.

Antifungal activity

Oxovanadium (IV) complexes may act as effective fungicides with low environmental impact and toxicity (Takino *et al.*, 2001). Synthesized compounds were carried out against two fungi, i.e., *Aspergillus spp.* and *Fusarium spp.*, and were found to be effective (**Figure 6)**.

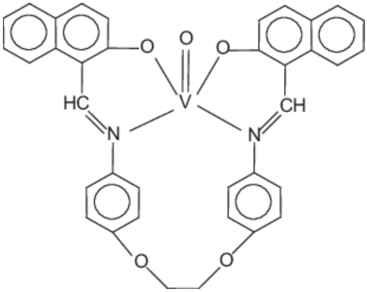


Figure 6: Structure oxovanadium (IV) complex having potential antifungal activity.

Antidiabetic properties

Diabetes is a chronic disease in which there is too high blood sugar level. Diabetes can be classified into three basic classes: type I, type II, and gestational diabetes. Type I is insulin-dependent diabetes; it is due to the deficiency of Insulin in the body and its control depends on the intravenous supply of insulin. Insulin is a hormone that controls glucose levels normally by promoting glucose uptake by the liver, gut, and peripheral tissues. Such action can be mimicked by triazole-based Schiff base oxovanadium complexes.

John McNeill (1985) initiated the research on the anti-diabetic activity of vanadium by monitoring the cardiac function of rats treated with the supply of vanadyl sulfate. The tests were carried out to determine the effects of different compounds of vanadium in treated diabetic animal models and *in vitro* assays (Mishra *et al*., 2018). Because of the limited absorption of vanadium by the intestinal lining, organo-vanadium complexes were synthesized to improve absorption (Tyagi *et al*., 2017). Studying oxovanadium complexes is more important for improving the treatment of diabetes since they have insulin-mimicking effects on hypoglycemia, which accounts for the beneficial and long-lasting effects of vanadium complexes in diabetic conditions (Cong *et al*., 2016).

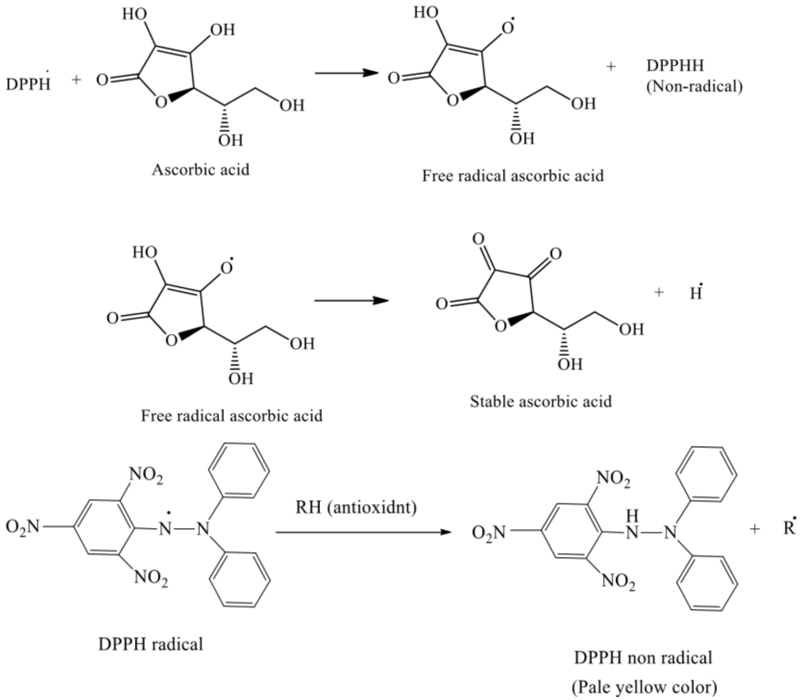
The bis(maltolato) oxovanadium(IV) complex, synthesized in 1992, displayed high hypoglycemic activity in animals under probes, with roughly 1.5 times the activity of $VOSO_4$ in chronic treatment and 3 times the activity of vanadyl sulfate in acute treatment protocols (Mishra *et al*., 2018). Extensive efforts have been made to synthesize and investigate various metal complexes as potential solutions to overcome the challenges posed by painful insulin injections and their side effects. In the search for effective diabetes medications, there is an active search for inhibitors of the carbohydrate-digesting enzyme α-amylase inhibitors that are currently used in clinical practice due to their ability to regulate the high blood glucose content after meals, highlighting the performance of α-amylase inhibitors as an integral part of diabetes treatment (Sharma *et al*., 2012). The synergistic action of metformin, Schiff base ligands, and oxovanadium (IV) contributes to their antidiabetic effects. Metformin acts as an insulin sensitizer, promoting the cellular insulin response, while the Schiff bases and oxovanadium(IV) provide additional mechanisms for glucose regulation (Liu *et al*., 2014).

The application of vanadium (V) for the medication of diabetes mellitus dates back to before the discovery of insulin (Hou *et al*., 2019). In the context of animal model systems and the cell cultures, vanadium ion and its compounds have established notable insulin-like and anti-diabetic activity, such as improving glucose regulation and metabolism in hepatocytes, adipocytes, and skeletal muscle, exciting glycogen synthesis and stimulating lipogenesis as well as preventing lipolysis and protein catabolism (Pessoa *et al*., 2015).

Anti-oxidant property

An antioxidant has the capability to hinder the oxidation process of other molecules. Since the oxidation reaction can generate free radicals, it can lead to the damage of cells due to the free radical chain reactions. Antioxidants terminate the chain reactions and lessen the effects of oxidation reactions. Transition metal complexes have shown significant antioxidant properties. Oxovanadium (IV) complexes possess a good DNA-binding capability, which is recognized worthy of studying the antioxidant capacity of those complexes. Free radicals play a dominant responsibility in the disease-causing ability of various microbes in humans and aging. Within food items, free radicals can lead to deterioration, causing a destruction in both flavor and the duration of shelf-life. Antioxidants are therefore shielding agents for the damage from free radicals to protect health. Researchers have discovered that ligand displayed low-scavenging ability in all the screened concentrations; however, upon complexation with oxovanadium ions, antioxidant potency has been intensified remarkably through oxidation of VO^{2+}(IV) to VO^{+}(V) using water as a medium in the reaction mixture (Lima *et al.*, 2021). It has been speculated that the greater extent of resonance of free radicals due to the coordination of the organic ligand to the metal ions through N-, S-, or O- increases the stabilization of free radicals. Supplementarily, it has been confirmed by the noted discoloration of purple DPPH solution demonstrating the stabilization of the DPPH radicals through the hydrogen deduction.

A simple and quick way to evaluate antioxidants using spectrophotometry is the DPPH assay. It is a quick, easy, accurate, and low-cost assay for determining the capacity of various compounds to serve as free radical stabilizers or proton donors (Gulcin *et al.*, 2023). DPPH (1,1-diphenyl-2-picryl-hydrazyl) is a stable radical containing an unpaired electron in its nitrogen bridge, which resulted in a violet-colored solution when dissolved in ethanol. DPPH free radical is reduced in the presence of an antioxidant agent generating a colorless ethanol solution which is the basis of the popular DPPH antioxidant assay.



Scheme 2: DPPH mechanism of antioxidant behavior.

Antioxidants also have anti-inflammatory, anti-cancer, and anti-tumor properties. Such behaviors may also be correlated to the antioxidant potency. Cell damage due to free radicals can be considered to show a key position in the aging and the progression of cancer, atherosclerosis, diabetes, and neurodegenerative disorders. Thus, antioxidants are the key agents for the defense against annihilation caused by free radicals. Pollution, cigarette smoking, the use of drugs to treat illness, stress, and even exercise can all contribute to an increase in free radical exposure (Barfeie, 2018).

Human pancreatic α-amylase

Human pancreatic α-amylase (HPA) is an enzyme belonging to the family of α-amylases, which is a singular polypeptide chain composed of 496 amino acid residues. The crystallographic structure of human pancreatic α -amylase shows α/β fold, which is a common protein folding motif. The exact atomic structure of human pancreatic α-amylase explains its method of action and contributes to the development of inhibitors and drugs targeting this enzyme (Mishra *et al.*, 2018).

Figure 7: Human-pancreatic α-amylase [PDB ID: 5E0F]

The α-amylase catalyzes a wide range of glycosidic bond cleavages, including gly- and deglycosylation, hydrolysis, and cyclization. HPA hyperactivity has been accompanied by type II diabetes, therefore regulating the enzyme is significant (Mishra *et* al., 2018). The enzyme, α-amylase participated in the carbohydrate metabolism inhibition for the cure of diabetes. Acarbose, a pseudo tetrasaccharide, effectively inhibits *in vitro* and *in vivo* enzymes like maltase, sucrose, glucoamylase, dextrinase, and α-amylase. Acarbose and voglibose are both oral inhibitors employed to target the α-amylase enzyme. (Tyagi *et al.*, 2017).

Alpha-amylase is found in salivary and pancreatic secretions in humans. Different organisms share approximately 30% amino acid sequence of α-amylase; all of those belonging to the glycosyl hydrolase family (Janeček, 1997). The cleavage of the inner and long chain of starch, α-1,4-glucan, and glycogen is catalyzed by α-amylase, which is a glycoprotein in nature.

Catalytic applications

Vanadium complexes can be employed in organic synthesis through oxidation catalysis. It is due to the fact that vanadium facilitates its use in Lewis acid-catalyzed and redox reactions, such as the ability to easily transition between different oxidations, several coordination numbers, strong attraction for oxygen, and a Lewis acid-like behavior (da Silva *et al.*, 2011).

Moreover, a great deal of catalysis, predominantly photocatalysis through the use of transition metal/metal oxide composites (similar to those of vanadium) has been employed in environmental detoxification (Sapkota *et al.*, 2019, Shrestha *et al.*, 2022). Composites of transition metal oxides such as ZnO-SWCNT, CuO-SWCNT (Sapkota *et al.*, 2020), CuO-ZnO (Sapkota *et al.*, 2021), and ZnO/ZnS/g-C3N4 (Hanif *et al.*, 2022) have been reported to have notable photocatalytic performance for the decay of stubborn water pollutant organic dyes. Double-layer carbon-encapsulated silver nanoparticles have displayed superb performance in anticancer and antibacterial activities (Islam *et al.*, 2021). Although the studies involving the use of vanadium complexes for catalysis are found in the literature, a great deal awaits further investigations and advancements.

Conclusions

Vanadium, a steel-grey colored corrosion-resistant metal, has several desirable characteristics such as moderate hardness, ductility, and an exceptionally high melting point of 1929 °C. It resists alkalis, sulfuric, and hydrochloric acids and has good corrosion resistance. Its peculiar characteristics are that it is electrically conductive but thermally insulating. Oxovanadium(IV) complexes with Schiff bases have been revealed as potential candidates to be used as effective antibacterial, antifungal, antiviral, anticancer, and insulin-mimetic agents. The versatile applicability of the complexes is attributed to the low production cost, easy availability, low toxicity, the ability to combat multi-drug resistant microorganisms, potency to behave as an insulin-mimetic agent and contribute to catalysis.

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