JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Views on Synthesis, Properties and various Practical Applications of Vanadium Pentoxide (V_2O_5)

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Abstract:

Vanadium pentoxide (V_2O_5) is a significant chemical due to its various properties and widespread application in a wide range of industries. When powdered, V_2O_5 has a yellow-to-orange or brownish tint and is a significant catalyst in chemical processes, particularly in the manufacture of sulfuric acid. It is important in electronics, notably in rechargeable lithium-ion batteries. V_2O_5 is also utilized in ceramics, specialized glass production, and the synthesis of specific dyes and pigments. Its unique features and functionality make it a key component in modern industrial processes, allowing for advancements in a wide range of scientific and commercial fields. The additive V_2O_5 vanadium pentoxide combination was predicted to improve the characteristics of ferrites and aid the development of ceramics technology.

Keywords: Vanadium pentoxide; V_2O_5; Vanadium Compounds; Synthesis of V_2O_5

1. Introduction to the Nature of Vanadium Pentoxide V_2O_5

Vanadium pentoxide (V_2O_5) has a fascinating history that includes both scientific discoveries and industrial applications: While working at an iron mine in 1830, Swedish scientist Nils Gabriel Sefström uncovered vanadium. He named it "vanadium" after the Scandinavian goddess Vanads, who was noted for her beauty and grace [1]. Friedrich Woehler verified a year later, in 1831, that this element was the same as the one identified by Del Rio in 1801 [2]. Vanadium pentoxide is the most significant vanadium chemical from an industrial standpoint. It is frequently utilized as an industrial catalyst and is the primary precursor of vanadium alloys. Sulfuric acid was transformed into a low-cost commodity chemical with the discovery of a simple reaction catalysed by V_2O_5. This reaction takes place between 400°C and 620°C, making V_2O_5 an important catalyst [3]. Shcherbinaite is a mineral form of V_2O_5 that is highly uncommon and nearly invariably found around fumaroles. The mineral trihydrate $V_2O_5.H_2O$ is also known as navajoite. V_2O_5 has sparked in a variety of scientific and technical fields since its first synthesis. Researchers are still investigating its characteristics and uses, making it an intriguing chemical in the realm of chemistry. Vanadium pentoxide (V_2O_5), or vanadia, is a chemical compound with the formula V_2O_5 [4]. It is a brown/yellow solid with a deep orange tint when freshly precipitated from an aqueous solution. Let's have a look at some noteworthy facts about this compound: The chemical formula is V_2O_5. With the Molar mass: about 181.88 g/mol, Solid brown/yellow (turns brilliant orange when freshly precipitated) It has a density of 3.35 g/cm. Melting point: 3.681°C (1,258°F; 954 K). 1.750°C (3,180°F; 2,020 K) boiling point decomposes [5]. The solubility in water is approximately 0.7 g/L at 20°C [6]. Orthorhombic crystal structure with a space group Coordination of Pmmn Trigonal bipyramidal (V) geometry is distorted [7]. The heat capacity is 127.7 J/(molK); The typical molar entropy in thermochemistry is 131.0 J/(molK) [8]. Formation Enthalpy Standard: Gibbs energy is -1550.6 kJ/mol. The term for free energy is -1419.5 kJ/mo. Vanadium pentoxide has the following peculiar properties: It is an amphoteric oxide, which means it may react with both acidic and basic materials. It is an important oxidizing agent in industrial processes and a primary precursor of vanadium alloys. Shcherbinaite, a mineral version of this chemical, is highly uncommon and is generally found around fumaroles [9]. Despite the fact that vanadium (atomic number 23) is mined fresh, it is precipitated from aqueous solution with a vivid orange hue. It functions as both a nanotech oxide and an oxidizing agent due to its hard oxidation state. Vanadium is a transition element with attractive various hues and reflecting qualities, as well as being light in weight and highly hazardous in nature. However, when heated, it changes appearance; the outer vanadium surface can be dissolved to appear extremely silvery [10]. It is the most significant molecule frequently employed as an industrial catalyst in organic synthesis since it is the primary precursor. Nowadays, vanadium is mostly used in steel hardening and strengthening. Such steel and sharp devices are often created. A catalyst is something that changes the oxidation state of a chemical process. Vanadium functions as a good catalyst in many chemical processes because it occurs in a variety of oxidation states. Vanadium oxide has the formula V_2O_5 and is an inorganic neutral chemical. Because V_2O_5 contains a metal non-metal, we will regard it as an ionic molecule. In the manufacturing of sulfuric acid, vanadium oxide V_2O_5 is utilized as an efficient catalyst. A technical grade V_2O_5 is manufactured as a black powder that is primarily employed in the manufacturing of vanadium metal and ferrovanadium. This inquiry will be launched for the purpose of synthesizing V_2O_5 additive, which will only be mixed with magnetic and electrical qualities. The addition of V_2O_5 to the Ni-Zn ferrite decreases the system's sintering temperature and increases the density of the material, resulting in facile magnetization [11]. Remember that this intriguing chemical span the gap between chemistry and industry, making it an important player in a variety of applications. Certainly, Vanadium pentoxide (V_2O_5) is employed in a range of industries due to its unique properties. Here are a couple such examples:

2. Properties of Vanadium Pentoxide (V_2O_5)'s intriguing world

Vanadium Pentoxide (V_2O_5) is a chemical has piqued the interest of academics and scientists due to its fascinating features. Here are some literature-based findings:

2.1 Electronic Structure and Optical Properties:

The electrical structures of the three major vanadium oxides— V_2O_3, VO_2, and V_2O_5—have been thoroughly investigated. These materials are distinguished by their structural, electrical, optical, and magnetic characteristics techniques such as optical spectroscopy, photoemission spectroscopy (PES), X-ray absorption or emission spectroscopy (XAS, XES), photoluminescence (PL), Raman scattering, and scanning tunnelling microscopy (STM) have been used in experimental research. Theoretical simulations, like as density functional theory (DFT), have also helped us grasp their electrical band structures. The Vanadium pentoxide thin films have intriguing optical properties. Bandgap energy (Eg) is an important characteristic influencing material property that decreases with increasing temperature.

2.1 Optical Properties of Vanadium Pentoxide Thin Films:

In these materials, the most likely optical transition is a direct permitted transition. Researchers have investigated optical characteristics utilizing techniques such as absorption, reflection, and photoemission spectroscopy.

Figure 1. Different colour appearance in Vanadium compounds

3. Vanadium compounds

Some other **vanadium compounds** and their intriguing properties:

3.1 Vanadium (II) Compounds:

These substances function as reducing agents. Vanadium (II) chloride (VCl_2) is one example. Because of their capacity to transfer electrons, vanadium (II) compounds are used in a variety of chemical processes.

3.1 Vanadium (IV) Compounds:

Vanadium (IV) is most commonly encountered as vanadyl derivatives with the VO^{2+} core. One example is vanadyl sulphate ($VOSO_4$) [12]. When ammonium vanadate (NH_4VO_3) is successively reduced with elemental zinc, it generates various colours that correspond to the four oxidation states of vanadium [13].

3.1 Vanadium (V) Compounds:

These chemicals have an oxidizing effect. Vanadium pentoxide is a commercially viable catalyst for the manufacture of sulfuric acid. It is also utilized in the vanadium redox battery, which stores energy in all four oxidation states.

3.1 Oxyanions:

In aqueous solution, vanadium (V) produces a wide range of oxyanions. The predominance map suggests at least 11 species depending on pH and concentration. The major species at high pH is the tetrahedral orthovanadate ion (VO_3^{4-}). The chemistry and crystallography of vanadium (V) are comparable to those of phosphorus, and it is used in protein crystallography to better understand biochemistry [14].

3.1 Other Compounds:

Compounds like vanadium have lower oxidation states vanadium hexacarbonyl ($V(CO)_6$). Vanadium tetrathiovanadate ($[VS_4]^{3-}$) is analogous to the orthovanadate ion.

4. Structure of V2O5

V_2O_5 is a solid that varies in hue from yellow to orange. It is a semiconductor with fascinating optical features. The structural structure of vanadium pentoxide (V_2O_5) is fascinating. V_2O_5 crystallizes in the orthorhombic crystal system. The unit cell is the fundamental repeating unit of the crystal structure. V_2O_5 unit cells contain four vanadium atoms and ten oxygen atoms. Layers of Octahedra: The crystal structure is made up of alternating layers of vanadium-oxygen octahedra and oxygen atoms. These layers are piled on top of one other. Vanadium-Oxygen Octahedra: Each vanadium element in an octahedral form is surrounded by six oxygen atoms. The layers inside the crystal structure are made up of vanadium-oxygen octahedra that share edges and corners. Interlayer bonding: By attaching to the vanadium atoms in surrounding layers, the oxygen atoms between the layers produce strong V-O-V bridges [15].

5. Crystal structure of Vanadium pentoxide (V_2O_5)

Vanadium pentoxide (V_2O_5) has a complex structural structure. Its true crystal lattice structure is referred to as the monoclinic phase. In a complex design, layers of VO_5 square pyramids are linked. Here's a simplified representation of its crystal structure: The structure of vanadium pentoxide (V_2O_5) is intriguing. It is made up of linked layers of edge-sharing VO_5 square pyramids. Here is a simplified diagram of the structure of V_2O_5. This diagram depicts the arrangement of vanadium (V) atoms (represented by V) linked by oxygen (O) atoms (shown by O). These layers are layered on top of each other in a crystal lattice to form the true three-dimensional structure. Within the V_2O_5 crystal structure, each vanadium atom is connected to five oxygen atoms, generating a complicated network [16, 17].

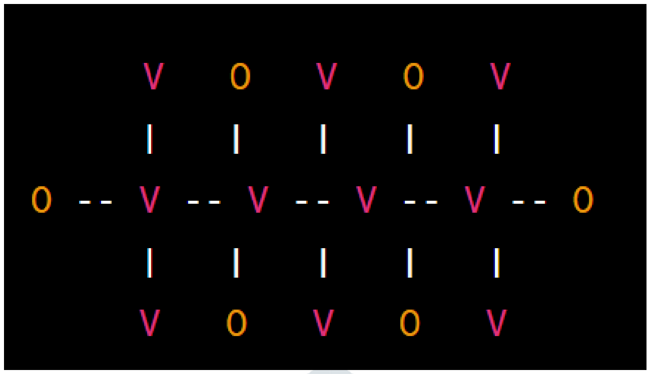

Figure 2. Crystal structure arrangement in Vanadium pentoxide V_2O_5

The interwoven layers of vanadium (V) and oxygen (O) atoms inside the crystal lattice structure are depicted in this picture. The real structure is three-dimensional, with these layers piled on top of each other in a precise order dictated by V_2O_5 crystallographic characteristics.

6. Synthesis of Vanadium pentoxide (V_2O_5)

There are several methods for manufacturing vanadium pentoxide (V_2O_5). Vanadium compound oxidation, such as vanadium oxides or vanadates, is a common process. Here's a general way for producing V_2O_5. The oxidation of vanadium compounds or vanadium-bearing minerals is a popular approach.

Method 1: Thermal Decomposition of Ammonium Metavanadate (NH_4VO_3)

Materials Required:

- Vanadium metal, vanadium oxides, or vanadates such as NH_4VO_3 (ammonium metavanadate), V_2O_4
- Oxidizing agent (such as concentrated nitric acid, hydrogen peroxide, or oxygen)
- Reaction vessel (made of glass or suitable material)
- A crucible and a furnace capable of reaching high temperatures (about 600-700°C) are required.
- Protective equipment (gloves, goggles, lab coat)
- Adequate ventilation is required since the procedure may produce ammonia gas.

6.1 Procedure:

Begin with a vanadium compound that includes vanadium in a lower oxidation state (vanadium oxides or vanadates, for example). In a crucible, place the ammonium metavanadate (NH_4VO_3) In the furnace, heat the crucible to roughly 600-700°C. Vanadium pentoxide and water vapor are formed when ammonium metavanadate decomposes [18]:

$$2\ NH_4VO_3 \rightarrow V_2O_5 + 2\ H_2O + 2\ NH_3\uparrow \quad (1)$$

After the volatilization of water and ammonia, vanadium pentoxide remains in the crucible. When employing a vanadium metal, it must first be oxidized to a lower oxide state (such as V_2O_4) before being further oxidized to V_2O_5. Fill the reaction vessel halfway with the vanadium compound. Gradually add the oxidizing agent. For example, if nitric acid is used, the reaction may entail heating the vanadium compound with strong nitric acid. To speed up the oxidation reaction, heat the reaction mixture. Temperature and time may differ depending on the individual reaction circumstances. Keep an eye on the reaction's progress. V_2O_5 may develop as a solid or as a coating on the reaction vessel. As needed for further usage or analysis, wash and dry the acquired V_2O_5 product. The reaction parameters, such as temperature, oxidizing agent, and starting materials, may differ depending on the synthesis process used and the required purity of the final V_2O_5 product.

Method 2: Oxidation of Vanadium (IV) Compounds

Another method includes oxidizing vanadium (IV) compounds to generate V_2O_5, which is generally accomplished with the use of oxidizing agents such as hydrogen peroxide or oxygen gas. By passing oxygen gas over a solid at high temperatures, vanadium (IV) oxide (VO_2) may be oxidized to V_2O_5:

$$2\,VO_2 + 1/2\,O_2 \rightarrow V_2O_5 \tag{2}$$

It should be noted that these processes are simplified and that exact control of parameters such as temperature, pressure, and reactant concentrations may be required for industrial-scale production. Safety precautions should also be taken, especially when dealing with potentially harmful substances and extreme temperatures [19].

7. Various Applications of V_2O_5

V_2O_5 is a multifunctional oxide that may be used in both energy-saving and energy-storage technologies. Its distinct electrical structure, which consists of three bands, results in fascinating optical characteristics and a multi-colour appearance. Nanomaterials and Gas Sensors**:** V_2O_5-based nanomaterials of diverse structures and chemical compositions have been produced. These materials are used in lithium-ion batteries (LIBs) as positive electrodes [20]. Furthermore, V_2O_5 has outstanding gas detecting characteristics, making it appropriate for gas sensors in pristine, doped, ornamented, and composite forms. Vanadium Pentoxide is a captivating material with a rich landscape of research and practical applications. Its properties continue to inspire scientific exploration and technological advancements. Because of its unusual structure and capabilities, V_2O_5 is used in catalysis, energy storage, and gas sensors [21].

- Catalysis: V_2O_5 acts as a catalyst in a number of chemical reactions, including the oxidation of sulphur dioxide (SO_2) to sulphur trioxide (SO_3), which results in the creation of sulfuric acid. It's also used in the oxidation of ammonia to produce nitric acid [22].
- Batteries and energy storage: VRFBs (vanadium redox flow batteries) rely largely on V_2O_5. Vanadium ions in various oxidation states are used to store energy in these batteries. VRFBs are commonly utilized in renewable energy systems to store grid electricity [23].
- Glass and ceramics: It enhances the colour and clarity of glass and ceramics. Color-changing pigments for glass and glazes are made from V_2O_5 [24].
- Metallurgy: It is utilized as a flux in the production of ferrovanadium and other vanadium alloys. The usage of V_2O_5 strengthens, hardens, and makes steel corrosion-resistant.

- Manufacturing of Chemicals: It is utilized in the production of sulfuric acid, phthalic anhydride, and maleic anhydride. V_2O_5 is used as a catalyst in oxidation processes.
- Environmental Applications: It is used to eliminate nitrogen oxide (NOx) from exhaust fumes in selective catalytic reduction (SCR) systems. V_2O_5-based catalysts help in the reduction of air pollution generated by automobiles and industrial activity [25].
- Research and Laboratory Reagents: Scientists employ V_2O_5 as a reagent in a number of chemical experiments. It is also used in spectrophotometry for analytical purposes.
- LIB Cathode Material: It has a direct impact on the performance of LIBs. To improve their electrochemical capabilities, researchers created a variety of V_2O_5- Vanadium pentoxide (V_2O_5) is essential in battery technology, especially in lithium-ion batteries (LIBs). Let's look at some of its uses: Because of its large theoretical capacity, V_2O_5 is regarded as a potential cathode material among metal oxides. Based nanomaterials with varying shapes and chemical compositions. 1D nanorods, nanowires, nanotubes, nanofibers, nanobelts, 2D nanosheets, and 3D hollow and porous nanostructures are examples of these nanomaterials. V_2O_5 nanocomposites with carbonaceous supports (amorphous carbon, carbon nanotubes, and graphene) have also been studied.
- Battery Advantages: V_2O_5 has several advantages: It has a big theoretical capacity and can hold a significant amount of charge. Low cost: V_2O_5 is a low-cost material for large-scale applications. Convenient synthesis: It can be produced by simple techniques. Chemical valence states include: This kind contributes to its battery effectiveness.
- Additional Applications: V_2O_5 is also used in electrochromic devices, which change color in response to an applied voltage. Photovoltaic cells: They help convert solar energy. V_2O_5-based materials increase energy storage in supercapacitors.

8. Health hazardous of Vanadium pentoxide (V_2O_5)

Vanadium pentoxide (V_2O_5) exposure can be hazardous to one's health. Let us look into the implications: Inhalation: For many days after being exposed to vanadium pentoxide, coughing may develop. Lung damage is a concern when inhaling significant amounts of V_2O_5 [26]. Skin Allergy: When V_2O_5 comes into contact with the skin, it can cause itching, redness, and an eczema-like rash. Even with modest future exposure, allergic reactions can emerge. Asthma-Like Allergy: Vanadium pentoxide can cause asthma-like symptoms [27]. Vanadium can produce nausea and vomiting if consumed. In animals, it may result in fewer red blood cells and higher blood pressure. Dosage, duration, and mode of exposure all have an impact on the consequences of [28].

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