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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ
«ХАЛЫҚ» ЖҚ

ХАБАРЛАРЫ

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ
КАЗАХСТАН»
ЧФ «Халық»

N E W S

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NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

ЧФ «ХАЛЫҚ»

В 2016 году для развития и улучшения качества жизни казахстанцев был создан частный Благотворительный фонд «Халык». За годы своей деятельности на реализацию благотворительных проектов в областях образования и науки, социальной защиты, культуры, здравоохранения и спорта, Фонд выделил более 45 миллиардов тенге.

Особое внимание Благотворительный фонд «Халык» уделяет образовательным программам, считая это направление одним из ключевых в своей деятельности. Оказывая поддержку отечественному образованию, Фонд вносит свой посильный вклад в развитие качественного образования в Казахстане. Тем самым способствуя росту числа людей, способных менять жизнь в стране к лучшему – профессионалов в различных сферах, потенциальных лидеров и «великих умов». Одной из значимых инициатив фонда «Халык» в образовательной сфере стал проект Ozgeris powered by Halyk Fund – первый в стране бизнес-инкубатор для учащихся 9-11 классов, который помогает развивать необходимые в современном мире предпринимательские навыки. Так, на содействие малому бизнесу школьников было выделено более 200 грантов. Для поддержки талантливых и мотивированных детей Фонд неоднократно выделял гранты на обучение в Международной школе «Мирас» и в Astana IT University, а также помог казахстанским школьникам принять участие в престижном конкурсе «USTEM Robotics» в США. Авторские работы в рамках проекта «Тәлімгер», которому Фонд оказал поддержку, легли в основу учебной программы, учебников и учебно-методических книг по предмету «Основы предпринимательства и бизнеса», преподаваемого в 10-11 классах казахстанских школ и колледжей.

Помимо помощи школьникам, учащимся колледжей и студентам Фонд считает важным внести свой вклад в повышение квалификации педагогов, совершенствование их знаний и навыков, поскольку именно они являются проводниками знаний будущих поколений казахстанцев. При поддержке Фонда «Халык» в южной столице был организован ежегодный городской конкурс педагогов «Almaty Digital Ustaz.

Важной инициативой стал реализуемый проект по обучению основам финансовой грамотности преподавателей из восьми областей Казахстана, что должно оказать существенное влияние на воспитание финансовой грамотности и предпринимательского мышления у нового поколения граждан страны.

Необходимую помощь Фонд «Халык» оказывает и тем, кто особенно остро в ней нуждается. В рамках социальной защиты населения активно проводится

работа по поддержке детей, оставшихся без родителей, детей и взрослых из социально уязвимых слоев населения, людей с ограниченными возможностями, а также обеспечению нуждающихся социальным жильем, строительству социально важных объектов, таких как детские сады, детские площадки и физкультурно-оздоровительные комплексы.

В копилку добрых дел Фонда «Халык» можно добавить оказание помощи детскому спорту, куда относится поддержка в развитии детского футбола и карате в нашей стране. Жизненно важную помощь Благотворительный фонд «Халык» оказал нашим соотечественникам во время недавней пандемии COVID-19. Тогда, в разгар тяжелой борьбы с коронавирусной инфекцией Фонд выделил свыше 11 миллиардов тенге на приобретение необходимого медицинского оборудования и дорогостоящих медицинских препаратов, автомобилей скорой медицинской помощи и средств защиты, адресную материальную помощь социально уязвимым слоям населения и денежные выплаты медицинским работникам.

В 2023 году наряду с другими проектами, нацеленными на повышение благосостояния казахстанских граждан Фонд решил уделить особое внимание науке, поскольку она является частью общественной культуры, а уровень ее развития определяет уровень развития государства.

Поддержка Фондом выпуска журналов Национальной Академии наук Республики Казахстан, которые входят в международные фонды Scopus и Wos и в которых публикуются статьи отечественных ученых, докторантов и магистрантов, а также научных сотрудников высших учебных заведений и научно-исследовательских институтов нашей страны является не менее значимым вкладом Фонда в развитие казахстанского общества.

С уважением,
Благотворительный Фонд «Халык»!

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DEVELOPMENT OF A NEW ENERGY-INTENSIVE VANADIUM ELECTROLYTE COMPOSITION AND INVESTIGATION OF REVERSIBLE CHARGE TRANSFER MECHANISMS FOR USE OF HIGH-EFFICIENCY ENERGY STORAGE DEVICES

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Abstract. The article provides a scientific analysis of the methods of creating electrolytes in international patent offices, scientometric databases in order to determine the optimal composition of the vanadium electrolyte composition with the ability to control the main parameters of electrolytic effects and the redox potential of vanadium compounds, to compile the basic material for creating the composition of electrolytes in energy-intensive storage, since energy–intensive storage with low cost is an actual material at the moment, in energy-saving technologies and energy issues of the industry.

The methodological and theoretical basis of the research is the work of domestic and foreign scientists devoted to the development of composite materials based on vanadium oxide materials and is based on elements of system analysis and modern generally accepted scientific methods, the choice of types and methods of evaluation.The forms of vanadium polynuclearity and kinetic characteristics of mutual transformations of vanadium ionic forms based on the charge transfer to the surface of a suspended polymer particle of vanadium-oxygen framework are studied. The processes of formation of the polynuclear forms of vanadium and the vanadium-oxygen framework are investigated, as well as the regularities and the relationship between the structure of the polynuclear ionic forms in solution are studied and the redox potential between vanadium ions with four possible degrees of oxidation, characterized by a variety of vanadium structures, is determined. Isomorphic substances consisting of trivalent vanadium, which are crosslinked into a vanadium oxygen framework, and are characterized by high resistance and strength of structures, have been identified. The results of the scientific analysis of the production of energy-intensive electrolytes based on vanadium oxide contribute to the disclosure of the practical potential of the use of vanadium electrolytes used in the production of batteries.

Keywords: vanadium oxide, energy intensity, electrolyte, energy storage, redox potential, vanadium-oxygen frame

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ЭНЕРГИЯНЫ КӨП ҚАЖЕТ ЕТЕТІН ЖАҢА КОМПОЗИЦИЯЛЫҚ ВАНАДИЙ ЭЛЕКТРОЛИТІН ӘЗІРЛЕУ ЖӘНЕ ЖОҒАРЫ ТИІМДІ ЭНЕРГИЯ САҚТАУ ҚҰРЫЛҒЫЛАРЫНДА ПАЙДАЛАНУ ҮШІН ҚАЙТЫМДЫ ЗАРЯД БЕРУ МЕХАНИЗМДЕРІН ЗЕРТТЕУ

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Аннотация. Мақалада электролиттік эффектілердің негізгі параметрлерін, ванадий қосылыстарының тотықсыздану әлеуетін басқару мүмкіндігімен ванадий электролитінің оңтайлы құрамын анықтау мақсатында халықаралық патенттік ведомстволарда, ғылымометриялық базаларда электролиттерді құру әдістемелеріне ғылыми талдау жүргізілді, энергосыйымды жинақтағыштарда қолданылатын электролиттердің құрамын жасау үшін негізгі материалды құрамдастырудың негіздері дайындалды, себебі, энергияны үнемдейтін технологиялармен өнеркәсіптің энергетикалық мәселелерінде қазіргі уақытта төмен құны бар энергияны көп қажет ететін жинақтағыштар өзекті материал болып табылады. Зерттеудің әдіснамалық және теориялық негізі ванадий оксиді материалдары негізінде композициялық материалдарды жасауға арналған отандық және шетелдік ғалымдардың еңбектері және жүйелік талдау элементтеріне және қазіргі заманғы жалпы қабылданған ғылыми әдістерге, бағалау түрлері мен технологиялық әдістерін таңдауға негізделген ғылыми әдістер болып табылады. Ванадийдің көп ядролылығының формалары, ванадийдің ілінген полимерлі бөлшегі-оттегі қаңқасының бетіне зарядтың ауысуы негізінде ванадийдің иондық формаларының өзара түрленуінің кинетикалық сипаттамалары зерттелінді. Ванадийдің көп ядролы формаларымен ванадий-оттегі қаңқасының қалыптасу процестері зерттелінді, сонымен қатар ерітіндідегі көп ядролы иондық формалардың құрылымы арасындағы заңдылықтармен қатынастар анықталынды және ванадий құрылымдарының әртүрлілігі мен ерекшеленетін мүмкін төрт тотығу дәрежесі бар ванадий иондары арасындағы тотығу-тотықсыздану потенциалдары анықталынды. Үш валентті ванадийден тұратын изоморфты заттар анықталынды, ванадий-оттегі қаңқасы және құрылымдардың жоғары қаттылығы мен беріктігімен ерекшеленетіні дәлелденді. Ванадий оксиді негізіндегі энергияны көп қажет ететін электролиттерді алудың ғылыми талдауының нәтижелері аккумуляторлар өндірісінде қолданылатын ванадий электролиттерін пайдаланудың практикалық әлеуетін ашуға ықпал етеді.

Түйін сөздер: ванадий оксиді, энергия сыйымдылығы, электролит, энергия сақтау, тотығу-тотықсыздану потенциалы, ванадий-оттегі қаңқасы

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РАЗРАБОТКА НОВОЙ ЭНЕРГОЕМКОЙ КОМПОЗИЦИИ ВАНАДИЕВОГО ЭЛЕКТРОЛИТА И ИССЛЕДОВАНИЕ МЕХАНИЗМОВ ОБРАТИМОГО ПЕРЕНОСА ЗАРЯДА ДЛЯ ПРИМЕНЕНИЯ В ВЫСОКОЭФФЕКТИВНЫХ НАКОПИТЕЛЯХ ЭНЕРГИИ

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Аннотация. В статье проведен научный анализ методик создания электролитов в международных патентных ведомствах, наукометрических базах с целью определения оптимального состава композиции ванадиевого электролита с возможностью управления основными параметрами электролитических эффектов и редокс-потенциалом соединений ванадия, для составления основного материала для создания композиции электролитов в энергоемкие накопители, так как, энергоемкие накопители с низкой себестоимостью – актуальный материал на данный момент в энергосберегающих технологиях и энергетических вопросах промышленности. Методологической и теоретической базой исследования являются работы отечественных и зарубежных ученых, посвященные разработке композиционных материалов на основе оксидных ванадиевых материалов, и

базируется на элементах системного анализа и современных общепринятых научных методах, выборе видов и методов оценки. Изучены формы полиядерности ванадия, кинетические характеристики взаимных превращений ионных форм ванадия на основе перехода заряда на поверхность взвешенной полимерной частицы ванадий-кислородного каркаса. Исследованы процессы становления полиядерных форм ванадия и ванадий-кислородного каркаса, а также изучены закономерности и взаимосвязь между строением полиядерных ионных форм в растворе и определен окислительно-восстановительной потенциал между ионами ванадия с четырьмя возможными степенями окисления, отличающимися разнообразием структур ванадия. Выявлены изоморфные вещества, состоящие из трехвалентного ванадия, которые сшиваются в ванадий кислородный каркас, и отличаются высокой стойкостью и прочностью структур. Результаты научного анализа получения энергоемких электролитов на основе оксида ванадия, способствуют раскрытию практического потенциала использования ванадиевых электролитов используемых в производстве аккумуляторов.

Ключевые слова: оксид ванадия, энергоемкость, электролит, накопители энергий, окислительно-восстановительный потенциал, ванадий-кислородный каркас

Introduction

An analysis of available technologies for obtaining vanadium electrolyte shows that at the moment vanadium flow batteries with vanadium electrolyte are used as energy storage devices, however, a number of scientists in the industrial and civil industries have modeled energy storage systems based on vanadium electrolytes, and in the short term of vanadium electrolyte production, energy storage sources represent a promising and inexpensive energy storage technology in on a large scale in various sectors of the economy (Aimbetova et al., 2023; Skyllas-Kazacos, 2022; Baeet al., 2020; Zhao et al., 2015). All this is due to the physicochemical properties of vanadium oxide: electrochemical activity, stability of the vanadium ion, a wide redox potential between different degrees of vanadium oxidation.

The creation of a new vanadium-containing electrolyte composition from industrial waste with energy-efficient properties, multicyclicity, high energy density and with a stable structure used in energy storage of traditional and alternative sources is becoming particularly relevant. The establishment of the charging/discharging mechanism of the obtained electrolytes and the scientific substantiation of methods for controlling the composition and electrochemical properties of a vanadium electrolyte by integrating charges into the vanadium-oxygen framework of a sulfuric acid solution is a scientific dilemma in a number of countries whose scientists are developing vanadium energy storage devices (Yang et al., 2017; Loktionovet al., 2022; Bahman et al., 2022). The most important economic indicator determined by the use of vanadium electrolyte in the civil and industrial sectors of the economy is its cost, but the duration of the process, the multicyclicity of up to 20,000 charge/discharge cycles, the high energy intensity of the vanadium-oxygen matrix in a sulfuric acid solution determine its prospects for further development. At the moment, there are problems with expanding the operating

temperature range, precipitation of various compounds in the electrolyte and the release of gases during the charging/discharging of electrolytes (Ngamsai et al., 2015; McCloy et al., 2022). To solve these problems, the authors (Meng-Yue et al., 2022) are working on optimizing the performance of vanadium electrolyte, acquiring output power with increased energy efficiency, the results of which will be used in the process of modeling vanadium electrolyte from industrial waste (Kolesnikova et al., 2022; Rodikova et al., 2019). Work is also underway to obtain a vanadium electrolyte based on oil production waste (Deniz et al., 2020).

The diagram of the ionic state of CV–pH in aqueous solutions is rather conditional and is used to systematize ionized forms of vanadium without taking into account their physicochemical properties.

Some scientists (Ingri et al., 1959) consider the ionic forms of vanadium in solution as a combination of VO^{2}+ and OH─ groups:

$[VO^{2+}(OH^{-})4]^{3-} \rightarrow [(VO^{2+})2(OH^{-})6]^{4-} \rightarrow [(VO^{2+})4(OH^{-})8]^{4-} \rightarrow [(VO^{2+})10(OH^{-})14]^{4-} \rightarrow VO_2 + OH^{-}$.

The presented combination in a wide pH range of 13.5-1.5 is not possible due to the absence of a dioxicate ion in the alkaline region, and a hydroxyan ion of vanadium in the acidic region.

The acidity of the medium is not the only control parameter for aqueous vanadium systems. A significant role is also played by the concentration of vanadium, changes in which can also lead to the transfer of ionized forms – this is precisely the phenomenon of self-organization that does not allow attributing a particular chemical formula to forms realized in solution.

Summarizing the above, the study of poly-nuclear forms of vanadium in sulfuric acid solutions is especially important in the development of new energy-intensive electrolytes based on vanadium oxide for the production of vanadium flow batteries with constructive solutions to increase energy intensity, high accumulation density, long service life and fast recharge. The scientific result in the form of the developed material is characterized by energy-saving properties of a wide range of applications due to possible integration with most energy sources.

Methodology and results

The methodological apparatus of the conducted research is based on the elements of system analysis and modern generally accepted scientific methods, the choice of types and methods of evaluation. Methods and forms of research include scientific and theoretical justifications (descriptive), experimental (laboratory, instrumental and test) studies.

The methods of collecting primary (initial) information, its sources and application for solving project tasks are based on the analysis of domestic/foreign literary and source materials using a systematic approach (Skyllas-Kazacos, 2011; Jung et al., 2012), as well as theoretical developments, laboratory and field experiments are the basis of our research, and they have an applied nature. The methodological and theoretical basis of the research will also be the works of domestic and foreign scientists devoted to the development of composite materials based on oxide materials.

There are updated methodological guidelines for conducting analytical and testing work, certified measurement methods, updated state standards, as well as other regulatory documents required by this project for conducting research.

To determine the optimal composition of a vanadium electrolyte with control over electrolytic effects and redox potential of vanadium compounds, a scientific analysis can be performed using various methods. Here are some key approaches that can aid in this analysis:

Electrochemical Characterization: Electrochemical techniques such as cyclic voltammetry, chronoamperometry, and impedance spectroscopy can be employed to investigate the behavior of vanadium redox couples in different electrolyte compositions.

Spectroscopic Analysis: Spectroscopic techniques, such as UV-Vis spectroscopy, infrared spectroscopy (IR), and X-ray absorption spectroscopy (XAS), can provide insights into the electronic structure and coordination environment of vanadium species in the electrolyte.

Density Functional Theory (DFT) Calculations: DFT calculations can be employed to simulate and predict the redox potential of vanadium compounds in different electrolyte compositions.

Thermodynamic Analysis: Thermodynamic modeling and calculations can be utilized to determine the equilibrium potentials and stability of different vanadium redox couples in electrolyte solutions.

Experimental Screening: Conducting a series of experiments with varying electrolyte compositions can help determine the influence of different parameters on electrolytic effects and redox potential.

Combining these methods and integrating experimental findings with theoretical calculations can provide a comprehensive scientific analysis of the optimal composition for a vanadium electrolyte, allowing for control over key electrolytic parameters and redox potential of vanadium compounds.

Results and discussion

Investigating reversible charge transfer mechanisms is essential for understanding the underlying electrochemical processes in VRFBs. The charge transfer mechanisms involve the reversible conversion of vanadium ions between different oxidation states during the charging and discharging cycles of the battery. By studying these mechanisms, researchers can identify key factors that affect the efficiency and performance of the battery.

The Sillen method assumes the presence of only one complex in the solution, secondly, the quantitative composition is limited by the general formula V[V(OH)]n, and the values of the polynuclearity of N, according to the calculation, respectively turned out to be equal to 9.5 and 32.3. This result contradicts the hypothesis of the uniqueness of the polynuclear complex, and the area of its existence is improperly stretched from pH 1.5 to 6.8 due to the stepwise dissociation of hexafasicdecavanadium acid. Perhaps this is justified to some extent from a chemical point of view, but it goes beyond the scope of the calculation method used. There are no compelling reasons of an energy or structural nature that lead to the stability of only a ten-core complex.

In VRFBs, the most commonly used polymer acid of vanadium is polyoxovanadate (POV). Polyoxovanadates are polymeric structures that consist of vanadium-oxygen clusters connected by bridging oxygen atoms. These clusters can be negatively charged, forming polyoxovanadate anions, which can act as acid species in the electrolyte solution.

Polyoxovanadate anions, such as $[VO_4]^{3-}$, $[V_2O_7]^{4-}$, or $[V_4O_{12}]^{4-}$, are capable of undergoing reversible redox reactions between different oxidation states of vanadium (typically V(IV) and V(V)) during the charging and discharging processes of VRFBs. These polymer acids of vanadium provide a means for energy storage and release by the transfer of vanadium ions and associated electrons.

During the charging process, V(IV) ions in the anode compartment undergo oxidation, releasing electrons and transforming into V(V) ions. These V(V) ions migrate through the ion exchange membrane to the cathode compartment, where they are reduced back to V(IV) ions. This reversible redox reaction allows for the storage and release of electrical energy.

It's important to note that the exact state and configuration of vanadium ions in the sulfuric acid system can vary depending on the specific operating conditions, concentration of sulfuric acid, and presence of other additives or supporting electrolytes. Additionally, the state of vanadium ions can be further influenced by factors such as temperature and pH, which can affect the redox potential and stability of the system.

Depending on the acidity of the medium, vanadium oxide can pass into both cationic and anionic forms when dissolved. In an alkaline medium at pH >12, vanadium oxide passes into the orthovanadate ion by reaction:

$$V_2O_5 + 6OH^- \leftrightarrow 2[VO_4^{3-}] + 3H_2O, \quad (1)$$

and in an acidic medium at pH < 1.5, it passes into the dioxide ion by reaction:

$$V_2O_5 + 2H^+ \leftrightarrow 2VO_2^+ + H_2O. \quad (2)$$

One indisputable conclusion follows from the diagram of the ionic state of vanadium: between the extreme monomeric forms of VO_2^+ and VO_4^{3-} there is a wide area of polymer ionized and neutral vanadium compounds.

Below is a diagram of the conversion of vanadium solutions in the vanadium-oxygen system.

Kinetic characteristics of mutual transformations of vanadium ions in technology are more important than their polynuclearity. However, the number of researches devoted to the kinetics of mutual transformations of polymer vanadium ions is limited. The charge on the surface of a suspended polymer particle is one of the main factors stabilizing the system. To ensure mutual transformations of ionized forms of vanadium, it is necessary to either suppress or change this charge on the surface of the particle. The easiest way to manage these processes is by chemical means, selecting the acidity of the medium at which the desired transformation is carried out.

Based on the framework model and bearing in mind that the formation occurs as a result of polycondensation reactions of the simplest vanadium ions, namely VO_2^+ or VO_4^{3-}, but it is ridiculous to assume that a cation can exist in an alkaline and an anion in an acidic region. Apparently, the speed of their transformation into each other is great.

However, there is a barrier that nature has created in the form of a neutral supramolecular compound - $n[VO_2^+ \cdot VO_3^-] \cdot yH_2O$ and high energy costs are required to break out of this potential pit. Probably, the bond of the VO_2^+cation and the VO_4^{3-}-anion is carried out through the $[VO_4]$ – tetrahedron (Figure 2), which forms a polymer vanadium-oxygen framework (Peng et al., 2023). The formation of the framework proceeds faster in an acidic and alkaline medium than in a neutral medium.

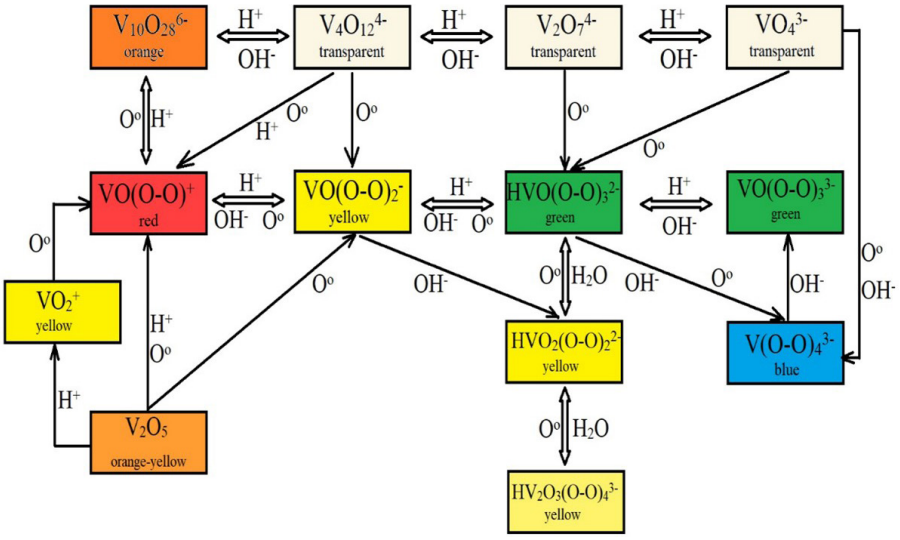
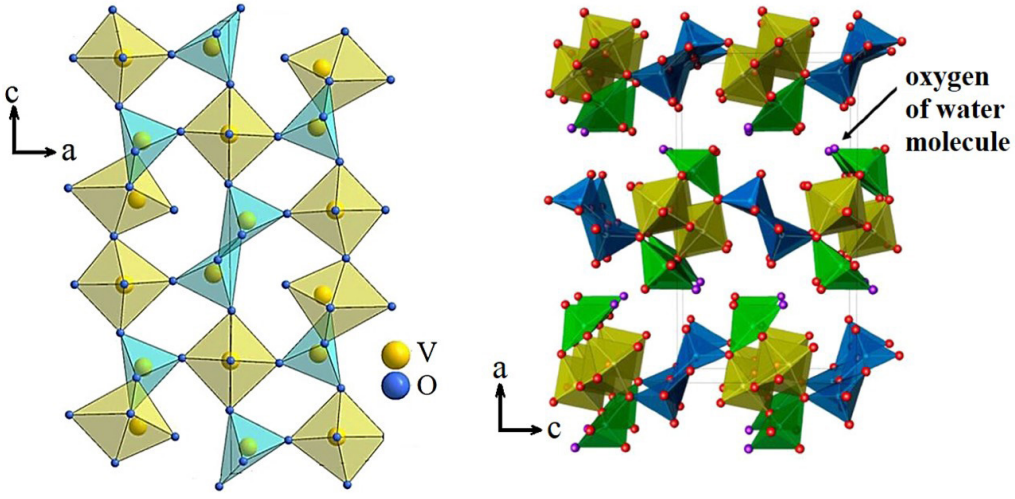


Fig. 1. Scheme of conversion of vanadium oxide compounds in solution



a) b)

Fig. 2. Structure of polynuclear forms of vanadium acid in solutions: a) tetrahedron; b) octahedra, polyhedral with oxygen of water molecule

Methods for creating vanadium electrolytes, especially in the context of vanadium redox flow batteries (VRFBs). Vanadium electrolytes are crucial for the functioning of

vanadium batteries, which have attracted attention as a promising technology for storing energy on a grid scale. The scientists who developed the concept of vanadium redox flow batteries conducted extensive research on the design and optimization of vanadium electrolytes (Skyllas-Kazacos, 2022). There are also works on the creation of vanadium electrolytes with improved performance and electrolyte stability by structuring new vanadium complexones, including the effect of electrolyte composition, pH and additives on battery performance (Zhang et al., 2020). This technique is characterized by high energy efficiency and cyclic stability of the vanadium electrolyte. A technique has been developed for creating new vanadium complexes with improved electrochemical properties in order to increase the stability, capacitance, electrochemical reversibility of vanadium electrolytes and service life (Zhang et al., 2017). South Korean scientists (Sun, 2020) have created vanadium electrolytes for high-performance vanadium batteries. The structure of vanadium electrolytes and electrochemical properties of new compounds of the composition of vanadium oxides have been revealed. At the same time, attention is paid to the overlap of the electrolyte and increasing the capacity of vanadium batteries.

The above works, along with many others, have made a significant contribution to the understanding and improvement of vanadium electrolytes. Their work covers various aspects, including electrolyte composition, stability, redox kinetics and electrochemical characteristics. By developing the knowledge and technology of vanadium electrolytes, these researchers have played a crucial role in the development and commercialization of vanadium battery technology for large-scale energy storage systems.Summarizing the above, the main methodology for composing a vanadium composition as electrolytes consists of the following principles of work.The vanadium electrolyte is typically prepared by dissolving vanadium compounds, such as vanadium pentoxide (V_2O_5), in a suitable aqueous solution. Sulfuric acid (H_2SO_4) is commonly used as the solvent to provide the necessary protons for the redox reactions and maintain conductivity. The preparation typically involves the following steps:

Synthesis of Vanadium Electrolyte Solutions: Vanadium electrolytes for VRFBs consist of vanadium ions in different oxidation states (typically V^{2+} and V^{3+}). The synthesis typically starts with dissolving vanadium compounds, such as vanadium pentoxide (V_2O_5) or vanadium sulfate ($V_2(SO_4)^3$), in a suitable solvent, such as sulfuric acid (H_2SO_4) or a mixture of sulfuric acid and water. The concentration and ratio of vanadium ions in different oxidation states are adjusted to achieve the desired redox potential and electrochemical performance.

Electrolyte Characterization: The synthesized and conditioned vanadium electrolyte is then characterized through various analytical techniques, such as spectrophotometry, cyclic voltammetry, or elemental analysis, to determine the concentration, redox potential, and overall quality of the electrolyte solution. In vanadium batteries, the vanadium electrolyte consists of two redox couples: V^{2+}/V^{3+} and V^{4+}/V^{5+}. These redox couples facilitate the reversible conversion between different oxidation states of vanadium ions during charging and discharging. To maintain the charge balance and prevent cross-contamination of the electrolyte, separate electrolyte tanks are used for

each redox couple. This design allows the vanadium ions to flow through a porous membrane, enabling the electrochemical reactions while keeping the two electrolytes physically separated. The structure of vanadium batteries can be explained by the following figure (Figure 3).

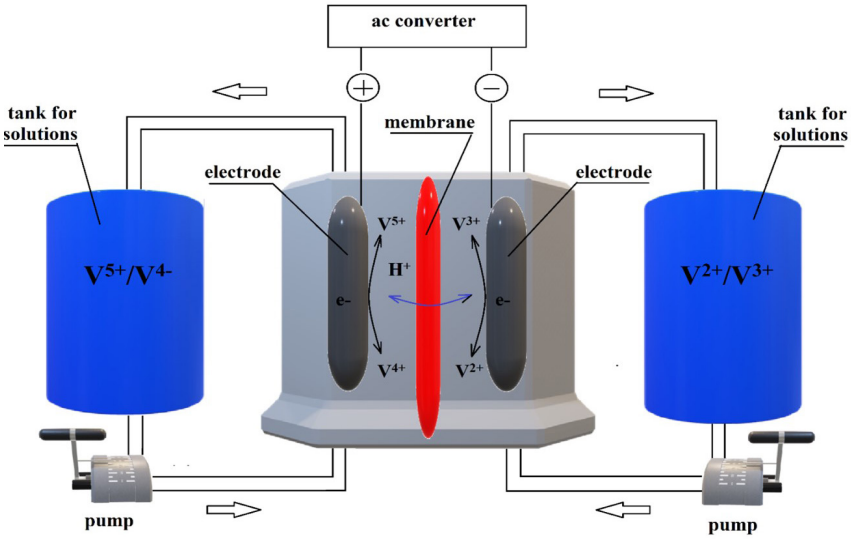


*Fig.3.*Structure of vanadium batteries

The structure of vanadium batteries, allows for the decoupling of energy storage capacity from power capacity. This design feature makes VRFBs suitable for applications that require flexible energy storage with long cycle life and deep discharge capabilities, such as grid-scale energy storage and renewable energy integration.

There are two main methods of electrolyte preparation: electrolysis and chemical reduction. In the preparation of the electrolyte, the method of reduction is used first and then electrolysis. Pentavalent vanadium is rapidly dissolved and reduced to a tetravalent crude solution using a reducing agent, and then further electrolytic reduction is carried out using an electrolysis device to obtain a 3 and 5 valence electrolyte. It is known that in sulfuric acid solutions, vanadium ions have four degrees of oxidation, which form two redox pairs: V^{2+}/V^{3+} и VO_2^{+}/VO^{2+} (Fu, 2021). The cathode and anode reactions of vanadium oxides can be represented as:

$VO_2^{+} + 2H^{+} + e^{-} \leftrightarrow VO^{2+} + H_2O$ (cathode)

$V^{2+} - e^{-} \leftrightarrow V^{3+}$ (anode)

The above reactions are the basis for creating a vanadium battery, that the degree of oxidation of vanadium on the cathode electrolyte varies in the intervals of +2 or +3, also the change in the degrees of oxidation of vanadium on the anode electrolyte varies by +4 or +5, the difference of which gives a high voltage of energies.

Conclusion

As a result of research on the scientific analysis of the preparation of vanadium electrolytes, the concept of high purity of the electrolytes obtained has been established,

since the polynuclear forms of vanadium acid with sulfuric acid media, depending on the impurity components, can change the electrochemical properties of their compounds. It was found that the solubility of the compound V_2O_5 in water (0.07 g/ l) and sulfuric acid depends on the concentration and temperature, the most optimal option was the reduction to tetravalent vanadium with high solubility using oxalic acid or other reducing agents. In the future, we will investigate the production of high-purity vanadium from vanadium-containing slags and spent vanadium catalysts, leached with a sulfuric acid solution, by repeated separation and purification by sorption-desorption. Vanadium electrolyte is an electroactive material for energy storage and the core of a vanadium battery, the cost of a vanadium electrolyte is 45-50% of the cost of all funds spent on vanadium batteries, the development of a highly efficient and inexpensive electrolyte preparation technology is a priority in the field of energy-efficient materials.

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