

MICELLAR SPECTROPHOTOMETRIC DETERMINATION OF VANADIUM(III) WITH BENZOHYDRAZIDE IN SODIUM DODECYL SULFATE MEDIUM

¹Muhammad Saleh Shar, ²Prof. Dr. Mushtaque Ali Jakhrani, ³Dr. Muhammad Aslam Korai

^{1,2,3}Institute of Chemistry, Faculty of Natural Sciences, Shah Abdul Latif University Khairpur

ABSTRACT

Trace metal determination is essential for environmental monitoring, industrial quality control, and public health. Conventional techniques such as AAS, ICP-OES, and ICP-MS are highly sensitive but require costly instrumentation and skilled operators. This study presents a simple, rapid, and green UV-Visible spectrophotometric method for determining vanadium(III) using benzohydrazide (BH) in sodium dodecyl sulfate (SDS) micellar medium, which replaces solvent extraction and reduces toxic solvent use. Solution pH, reagent and surfactant concentrations, complex stability, and foreign ion interference were optimized. The V(III)-BH complexes showed maximum absorbance at 517.4 nm, with good linearity and high molar absorptivity. The method gave satisfactory precision, good recoveries for certified reference materials, alloys, and tap water, and agreed well with AAS results. It offers a cost-effective, environmentally friendly alternative for routine vanadium analysis in laboratories lacking advanced instrumentation.

KEYWORDS: Trace metal determination; Micellar medium; Vanadium(III); Benzohydrazide; Sodium dodecyl sulfate; green UV-Visible spectrophotometric method

1. INTRODUCTION

Vanadium is a transition metal that occurs in oxidation states from +2 to +5 [1-3]. It is widely distributed in the Earth's crust and is found in fossil fuels, minerals and natural waters. It is also an important industrial element: most of it goes into ferrovanadium and high-strength, corrosion-resistant steel alloys, and smaller amounts into catalysts, ceramics, pigments and redox-flow batteries. Vanadium also has a biological side [4-6]. At trace levels it is considered beneficial or essential for some organisms, and some vanadium compounds have been studied for insulin-mimetic activity [7-10]. At higher exposures, however, it is toxic and can affect the respiratory, hepatic, renal and nervous systems. Industrial discharge, fuel combustion and the weathering of vanadium-bearing rocks continue to raise its levels in the environment, so reliable monitoring in water, alloys and biological matrices is needed [11,12].

The chemistry of vanadium makes its analysis difficult. Its toxicity, mobility and bioavailability depend on its oxidation state, so speciation matters as much as total content. V(III) is the less stable and less commonly studied state. It is readily oxidized by air and by other oxidants in solution, and it tends to hydrolyse as the pH rises. A method for V(III) therefore has to form a stable, well-defined complex quickly and keep it stable during measurement [13].

Several instrumental techniques are used for trace vanadium, including flame and graphite furnace atomic absorption spectrometry (AAS), inductively coupled plasma optical emission spectrometry (ICP-OES), ICP mass spectrometry (ICP-MS) and voltammetry [14]. They are sensitive and selective, but they require expensive instruments, trained operators, costly consumables and regular maintenance, which limits their use in many routine and resource-limited laboratories. Ultraviolet-visible spectrophotometry is a practical alternative because it is simple, fast, inexpensive and widely available. Its main limitations are modest sensitivity and selectivity, since many chromogenic reagents form complexes with several metal ions and give low molar absorptivity or unstable colors in purely aqueous media [15].

Micellar-enhanced spectrophotometry addresses these limitations. Surfactants aggregate into micelles above their critical micelle concentration (CMC). Micelles provide a microenvironment that can solubilise hydrophobic ligands and metal complexes, increase molar absorptivity, shift λ_{max} , stabilize the colored species and improve reaction rates [16]. They also make it possible to work in aqueous solution without toxic organic solvents, so the approach is also in line with green analytical chemistry. Sodium dodecyl sulfate (SDS) is an anionic surfactant that is cheap, readily available, stable and has a well-characterized CMC (about 8 mM in water at 25 °C). Its negatively charged micellar surface can concentrate cationic metal species at the micelle-water interface, so a metal-ligand complex forms in a more favorable environment than in bulk water [17].

Benzohydrazide (BH) is an acylhydrazide containing a carbonyl group and a terminal hydrazine group. It can tautomerise between keto and enol forms and coordinate metal ions as a bidentate chelating ligand through the carbonyl oxygen (or enolate oxygen) and the amino nitrogen [18]. Hydrazides and their derivatives are well known for their coordination chemistry and for forming colored complexes with transition metals, so they are attractive reagents for spectrophotometric work [19]. Their use together with surfactant media for trace

vanadium(III) is much less explored. To our knowledge, a simple method based on the BH-V(III) complex in an SDS micellar medium has not been reported in detail [20].

The present work therefore develops and validates a micellar spectrophotometric method for the determination of V(III) using benzohydrazide in SDS medium. The main variables (reagent and surfactant concentration, pH, order of addition, temperature, reaction time and stability of the complex) were optimized, and the stoichiometry of the complex was established by Job's method of continuous variations. The method was characterized by its linear range, molar absorptivity, Sandell's sensitivity, limits of detection and quantification, precision and accuracy, and the effect of diverse ions was studied. Its applicability was demonstrated on certified reference materials, alloys and tap water, and the results were compared with those of AAS. The aim of this study was to develop and validate a micellar spectrophotometric method for V(III) based on its reaction with benzohydrazide in SDS medium. The reaction conditions were optimised, the complex stoichiometry was determined, and the analytical performance and selectivity of the method were evaluated. The method was applied to certified reference materials, alloys and tap water, and the results were compared with AAS.

2. MATERIALS AND METHODS

2.1 Chemicals and Reagents

All chemicals employed throughout this investigation were of analytical reagent (AR) grade, and deionized water was used for the preparation of all solutions. Glassware was thoroughly cleaned with dilute nitric acid, rinsed several times with deionized water, and dried before use to minimize contamination from trace metal ions. Benzohydrazide (BH) was selected as the chromogenic complexing reagent because of its strong chelating ability toward transition metal ions. Sodium dodecyl sulfate (SDS) was used as the micelle-forming surfactant for solubilization of the metal-ligand complexes. Standard stock solutions of vanadium(III) and manganese(II) were prepared by dissolving appropriate quantities of their analytical-grade salts in deionized water and were subsequently diluted to the required working concentrations.

2.2 Instrumentation

The absorbance measurements were carried out using a PerkinElmer Lambda 365 UV-Visible spectrophotometer and a Cecil CE-9500 UV-Visible spectrophotometer equipped with matched 1.0 cm quartz cells (21). The solution pH was measured using a Sension 156 pH/conductivity/TDS meter, calibrated with standard buffer solutions prior to each set of experiments (22).

2.3 Preparation of Reagents

2.3.1 Benzohydrazide Solution

A 4.0×10^{-4} mol L⁻¹ benzohydrazide solution was prepared by dissolving 0.0544 g of benzohydrazide in a small volume of ethanol. The solution was transferred to a 1000 mL volumetric flask, followed by the addition of 3.0% SDS solution, and diluted to the mark with deionized water.

2.3.2 Sodium Dodecyl Sulfate Solution

A 3.0% (w/v) sodium dodecyl sulfate solution was prepared by dissolving 3.0 g of SDS in deionized water and diluting to 100 mL in a volumetric flask.

2.3.3 Buffer Solutions

Buffer solutions covering the pH range 1.0-9.5 were prepared according to standard analytical procedures. Hydrochloric acid-potassium chloride buffers were used for acidic media (pH 1-2), acetate buffers for pH 5-5.5, phosphate buffers for pH 6.5-8.0, and borate buffers for alkaline media (pH 9-9.5). The pH values were verified using the calibrated pH meter before use.

2.4 General Analytical Procedure

An aliquot of the sample solution containing the desired concentration of metal ion was transferred into a 10 mL volumetric flask. The required volume of benzohydrazide reagent was added, followed by 2.0 mL of 3.0% SDS solution. An appropriate buffer solution was then added to obtain the optimum pH for complex formation. Finally, the solution volume was adjusted to the mark with deionized water, thoroughly mixed, and allowed to stand for complete colour development. The absorbance of the colored complex was measured against a reagent blank prepared under identical conditions.

2.5 Optimization of Experimental Variables

To obtain maximum analytical sensitivity, several experimental parameters influencing complex formation were systematically investigated. These included the effect of solution pH, benzohydrazide concentration, and SDS concentration, as well as the metal-to-ligand mole ratio, the stability of the colored complex, the Beer's law concentration range, and the influence of foreign ions.

2.6 Determination of Vanadium(III)

The optimized experimental conditions for the determination of vanadium(III) were established as follows. The V(III)-BH complex showed maximum absorption at 517.4 nm at an optimum pH of 6.0. The optimum benzohydrazide concentration was 4.0×10^{-4} mol L⁻¹, and 2.0 mL of 3.0% SDS solution was used. The metal-

to-ligand ratio was found to be 1:2. Calibration standards were prepared within the concentration range of 0.12-5.0 $\mu\text{g mL}^{-1}$, and the calibration graph was constructed by plotting absorbance against concentration.

2.7 Analysis of Alloy Samples

Certified alloy reference materials containing vanadium was accurately weighed (0.1- 0.5 g) and transferred into clean borosilicate beakers. Each sample was digested with a mixture of concentrated hydrochloric acid and concentrated nitric acid to ensure complete dissolution of the metal matrix. The resulting solution was heated gently on a hot plate until near dryness, taking care to avoid spattering and loss of analyte. The residue was then cooled and dissolved in dilute hydrochloric acid and deionized water. After filtration to remove any insoluble residue, the digest was quantitatively transferred into a volumetric flask, and the filter paper was washed several times with deionized water, with the washings added to the flask. The solution was then diluted to the required volume with deionized water. Appropriate aliquots of the resulting sample solution were analysed for vanadium(III) following the general analytical procedure described in Section 2.4 under the respective optimum conditions. A reagent blank was prepared in the same way without the sample, and each determination was carried out in triplicate. The results were compared with the certified values of the reference materials to evaluate the accuracy of the proposed method.

2.8 Analysis of Water Samples

Tap water samples were collected from Khairpur City in pre-cleaned polyethylene bottles, which had been washed with dilute nitric acid and rinsed with deionized water. The samples were filtered through 0.45 μm membrane filters to remove suspended particulate matter and acidified with concentrated nitric acid to prevent precipitation and adsorption of dissolved metals on the container walls. The samples were stored at 4 °C and analysed as soon as possible after collection. Because the tap water contained no detectable vanadium under the proposed conditions, or only very low levels, the accuracy of the method was evaluated by recovery studies. For this purpose, known concentrations of vanadium(III) were added to the water samples before analysis. Appropriate aliquots of the original and spiked samples were then analysed according to the general analytical procedure described in Section 2.4 under the respective optimum conditions. The pH was adjusted with the appropriate buffer solution, and a reagent blank was prepared in the same way using deionized water. Each determination was carried out in triplicate, and the percentage recovery was calculated from the difference between the amounts found in the spiked and unspiked samples relative to the amount added.

2.9 Analysis of Certified Reference Materials

The applicability of the developed method was further evaluated using certified reference materials (CRMs), for the determination of Vanadium. Before analysis, the CRM was dried to constant mass according to the certificate instructions. An accurately weighed portion of the sample was transferred into a clean digestion vessel and treated with concentrated nitric acid. The mixture was heated gently until complete dissolution of the sample matrix was achieved and a clear solution was obtained. After cooling to room temperature, the digest was filtered if necessary, quantitatively transferred into a volumetric flask, and diluted to the mark with deionized water. Appropriate aliquots of the resulting solution were then analysed for vanadium(III) following the general analytical procedure described in Section 2.4 under the optimized experimental conditions (pH 5.5, 4.0×10^{-4} mol L^{-1} benzohydrazide, and 2.0 mL of 3.0% SDS). A reagent blank was carried through the whole digestion and measurement procedure, and each determination was carried out in triplicate. The accuracy of the method was assessed by comparing the vanadium content found with the certified value, and the results were expressed as percentage recovery.

2.10 Method Validation

The developed method was validated by evaluating the following analytical characteristics: Beer's law linearity, molar absorptivity, correlation coefficient (R^2), precision, accuracy, percentage recovery, percent relative standard deviation (%RSD), and selectivity toward foreign ions. The results were also compared with those obtained by Atomic Absorption Spectrometry (AAS). The obtained analytical results demonstrated excellent agreement with those obtained using the reference AAS method, confirming the reliability of the proposed spectrophotometric procedure for the routine determination of vanadium(III).

3. RESULTS AND DISCUSSION

3.1 Absorption Characteristics of Benzohydrazide

The absorption spectrum of benzohydrazide (BH) was first recorded in 3.0% sodium dodecyl sulfate (SDS) solution to establish its spectral behaviour before complex formation. The reagent exhibited a characteristic absorption maximum at 285.2 nm, confirming its suitability as a chromogenic ligand for transition metal ions. The blank solution showed negligible absorbance in the visible region, allowing accurate measurement of the coloured metal complexes. Figure 3.1 shows the UV-Visible spectra of benzohydrazide (BH) in 3.0% sodium dodecyl sulfate (SDS) solution (as shown in Figure: 1).

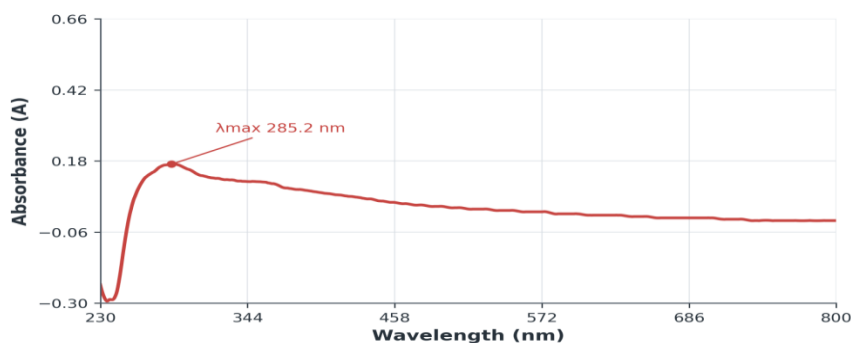


Figure: 1 The absorption spectrum of benzohydrazide (BH) was first recorded in 3.0% sodium dodecyl sulfate (SDS) solution

3.2 Formation of the Vanadium(III)-Benzohydrazide Complex

Figure: 2 shows the UV-Vis spectrum of the V(III)-(BH)₂ complex ($\lambda_{\text{max}} = 517.4 \text{ nm}$) in SDS. When vanadium(III) was reacted with benzohydrazide in SDS micellar medium under optimized conditions, an intense reddish-coloured complex was produced. The absorption spectrum exhibited a distinct maximum at 517.4 nm, indicating successful coordination between vanadium(III) and benzohydrazide. The presence of SDS played a significant role in increasing the intensity of the absorption band. The micellar medium solubilized the hydrophobic complex and produced a hyperchromic effect, leading to higher analytical sensitivity than conventional aqueous systems.

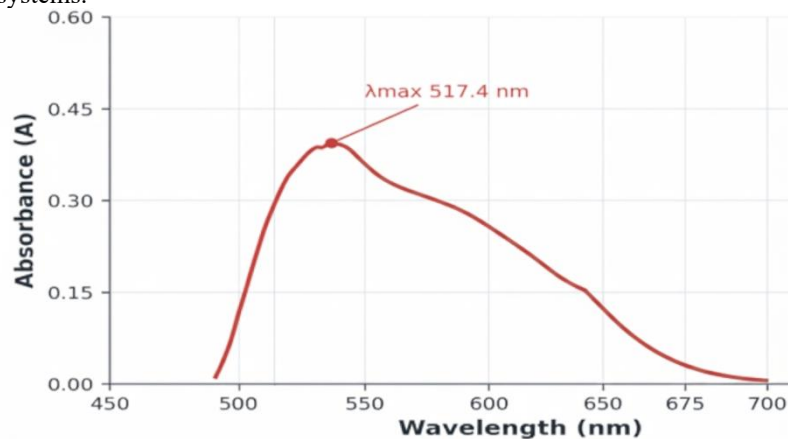


Figure: 2 The UV-Vis spectrum of the V(III)-(BH)₂ complex ($\lambda_{\text{max}} = 517.4 \text{ nm}$) in SDS.

3.3 Stoichiometry of the Vanadium Complex

The composition of the vanadium complex was investigated using the mole-ratio method. Maximum absorbance was obtained when the ligand-to-metal ratio corresponded to 2:1, indicating the formation of a stable V(III)-(BH)₂ complex. This stoichiometric ratio suggests that two benzohydrazide molecules coordinate with one vanadium ion through nitrogen and oxygen donor atoms, forming a stable chelate suitable for spectrophotometric determination (Figure: 3).

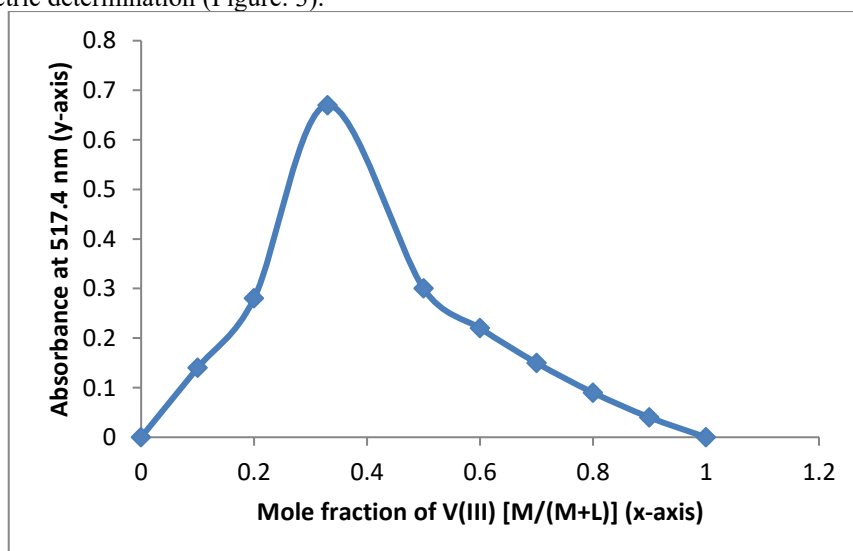


Figure: 3 Stoichiometry of the Vanadium Complex using the mole-ratio method.

3.4 Effect of Benzohydrazide Concentration

Figure: 4 shows the effect of BH concentration on the V(III)-BH complex. The influence of reagent concentration on complex formation was studied by varying the concentration of benzohydrazide while keeping all other experimental variables constant. The absorbance increased progressively with increasing reagent concentration up to $4.0 \times 10^{-4} \text{ mol L}^{-1}$, after which no significant increase was observed. Higher concentrations produced no analytical advantage, so $4.0 \times 10^{-4} \text{ mol L}^{-1}$ was selected for all subsequent investigations.

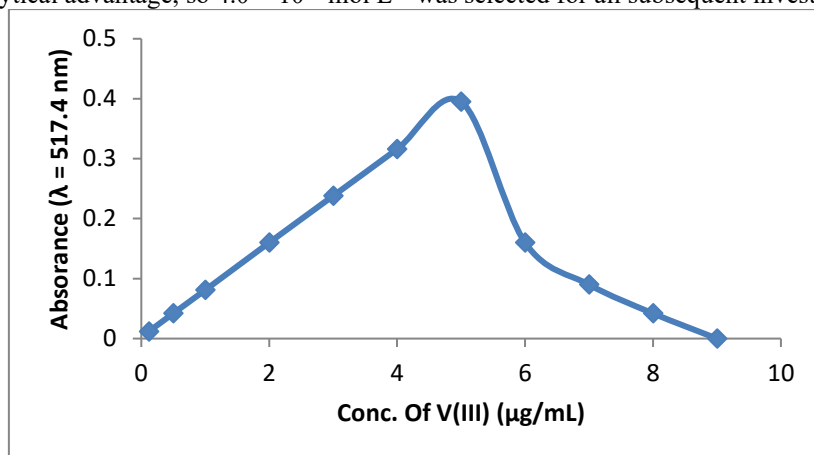


Figure: 4 The effect of BH concentration on the V(III)-BH complex

3.5 Effect of pH on Vanadium Determination

Figure: 5 shows the effect of pH on the absorbance of the V(III)-BH complex, with absorbance decreasing on either side of the optimum. The pH of the reaction medium is one of the most critical parameters affecting metal-ligand complexation. The absorbance of the V(III)-BH complex was investigated over a wide pH range. Maximum absorbance was obtained at pH 6.0, indicating optimum coordination between vanadium and benzohydrazide under slightly acidic conditions. At lower pH values, protonation of the ligand reduced its complexing ability, whereas alkaline media promoted partial hydrolysis of the vanadium ion.

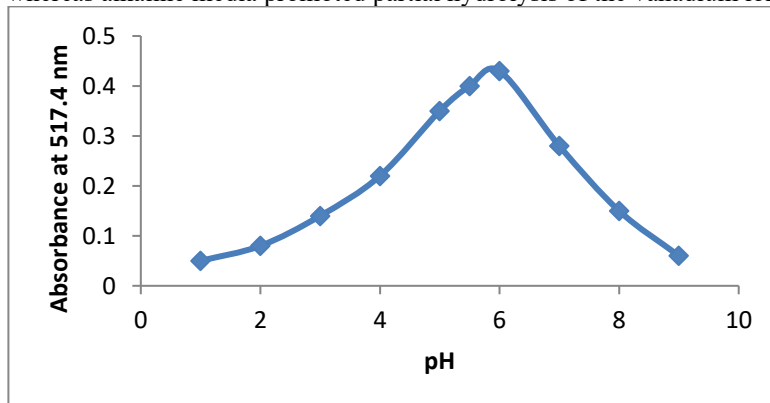


Figure: 5 The effect of pH on the absorbance of the V(III)-BH complex

3.6 Stability of the Vanadium Complex

Figure: 6 shows the stability of the V(III)-BH complex in 3.0% SDS. The stability of the coloured complex was examined by measuring the absorbance at different time intervals. The V(III)-BH complex remained stable for an extended period without noticeable loss of colour intensity. This excellent stability permits routine laboratory analysis without the need for immediate absorbance measurement and improves analytical precision.

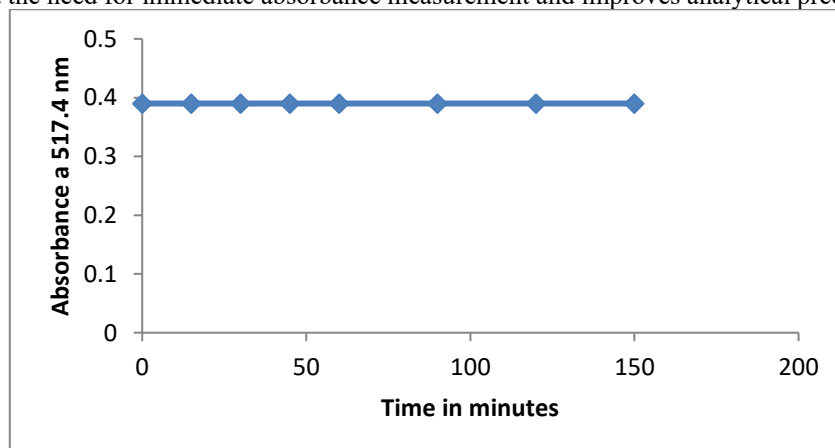


Figure: 6 the stability of the V(III)-BH complex in 3.0% SDS

3.7 Calibration Curve for Vanadium

Figure: 7 shows the calibration curve for the V(III)-BH complex. Calibration standards were prepared in the concentration range 0.12-5.0 $\mu\text{g mL}^{-1}$ under the optimized conditions, and the absorbance of each was measured at 517.4 nm against the reagent blank. The absorbance increased linearly with vanadium concentration, in agreement with Beer's law. The regression equation obtained was:

$$A = 0.0784C + 0.0023 \quad (R^2 = 0.9998)$$

where A is the absorbance and C is the concentration of V(III) in $\mu\text{g mL}^{-1}$. The high coefficient of determination confirms the excellent linear relationship between absorbance and vanadium concentration over the studied range. The small intercept, which is close to zero, indicates negligible blank interference. These results demonstrate that the developed method is suitable for the quantitative determination of vanadium(III).

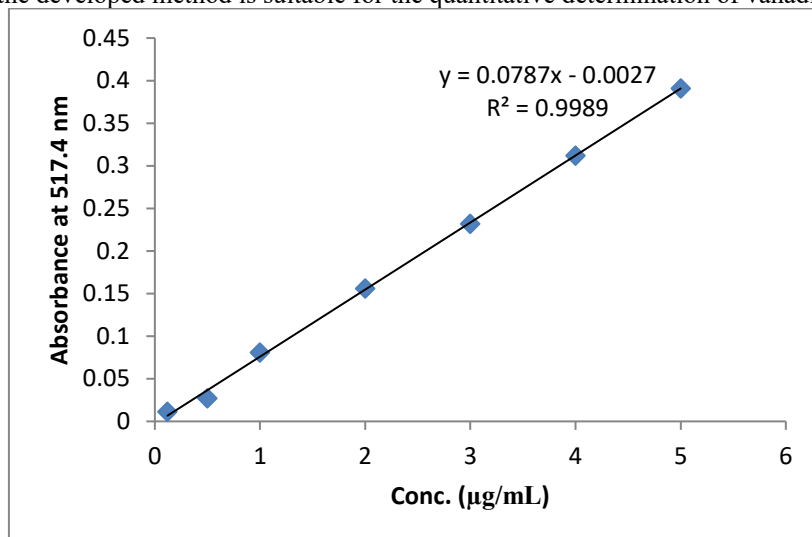


Figure: 7 The calibration curve for the V(III)-BH complex

3.8 Analytical Characteristics of the Vanadium Method

Under the optimized conditions, the proposed method showed its maximum absorbance at 517.4 nm. Beer's law was obeyed over the vanadium(III) concentration range 0.12-5.0 $\mu\text{g mL}^{-1}$, and the molar absorptivity was $3.72 \times 10^4 \text{ L mol}^{-1} \text{ cm}^{-1}$. The optimum pH was 6.0, and the best results were obtained with 3.0% SDS and a benzohydrazide concentration of $4.0 \times 10^{-4} \text{ mol L}^{-1}$. The metal-to-ligand ratio of the complex was 1:2. These parameters indicate that the proposed method has excellent analytical sensitivity.

Table: 1 Analytical parameters of V(III)-BH

Characteristics	V (III)
Beer's Law range $\mu\text{g mL}^{-1}$	0.12–5.0
Absorption max: λ_{max}	517.4 nm
Molar absorptivity L/mol.cm	3.72×10^4
pH	6
3.0% SDS	2.0 mL
BH	$4.0 \times 10^{-4} \text{ M}$
M : L Ratio	1 : 2
R^2	0.9996

3.9 Effect of Foreign Ions

The selectivity of the proposed method was evaluated by studying the interference of several commonly occurring ions. Large amounts of sodium tartrate, potassium thiocyanate, citrate, magnesium(II), zinc(II), cobalt(II), and manganese(II) did not interfere significantly. Only chromium(III), cadmium(II), lead(II), and iron(III) caused noticeable interference, and only at comparatively lower concentrations. These observations demonstrate the good selectivity of benzohydrazide in SDS micellar medium.

Table: 2 Effect of foreign ions on the V(III)-BH complex

Ion / Salt	V(III)
Na_2 tartrate, KSCN, KClO_3	1800
Mg(II)	900
$\text{Na}_2\text{C}_2\text{O}_4$	700
Na_2 citrate	800
Mn(II)	400
Zn(II)	300
Co(II)	380
KCN	150
Al(III)	150

Cu(II)	200
Cr(III)	8
Fe(III)	15
Pb(II)	30
Cd(II)	12

3.10 Recovery Study of Vanadium

The reliability of the developed method was evaluated by recovery experiments on tap water samples spiked with known amounts of V(III). The recovery was approximately 97%, confirming good analytical accuracy. This high recovery demonstrates that common matrix constituents do not significantly influence the determination. Table 4 shows the recovery test for V(III) added to tap water.

Table: 3 Recovery test for V (III) added to tap water

Amount added (µg)	1.7
Found (µg)	1.65
Recovery (%)	97.06

Determination of Vanadium in Alloy Samples

Table 4 shows the recovery test for V(III) in alloy samples. The proposed method was successfully applied to certified alloy reference materials containing vanadium. The analytical results agreed closely with the certified values, confirming the applicability of the developed method for industrial sample analysis.

Table: 4 Determination of Vanadium in a Alloy Samples

Alloy	Steel, S.A.E. No:6150
Composition of synthetic mixture (µg mL⁻¹)	V (0.2)
Found (µg mL⁻¹)	0.19
% Recovery	95

4. CONCLUSIONS

A simple, rapid, and environmentally friendly micellar spectrophotometric method was developed for the determination of vanadium(III) using benzohydrazide (BH) in sodium dodecyl sulfate (SDS) medium. The V(III)-BH complex formed an intense coloured product with maximum absorbance at 517.4 nm. SDS solubilized the complex in the aqueous phase, which removed the need for solvent extraction and enhanced the sensitivity of the method. Under the optimum conditions (pH 6.0, 4.0×10^{-4} mol L⁻¹ BH, and 2.0 mL of 3.0% SDS), the metal-to-ligand ratio was 1:2 and the complex remained stable for an extended period. Beer's law was obeyed over the range 0.12-5.0 µg mL⁻¹, with a molar absorptivity of 3.72×10^4 L mol⁻¹ cm⁻¹ and a correlation coefficient of 0.999. Most common ions did not interfere, and only Cr(III), Cd(II), Pb(II), and Fe(III) interfered at comparatively low levels. The method gave good recovery (about 97%) for V(III) added to tap water. It was also applied to an alloy sample and compared with AAS. The method is inexpensive, uses no toxic organic solvents, and needs only a standard UV-Visible spectrophotometer. It is therefore a suitable alternative for routine vanadium analysis in laboratories without advanced instrumentation.

REFERENCES

1. Shaheen, S.M., Mosa, A. and Rinklebe, J., 2022. Vanadium: Chemical properties, industrial use, global soil distribution, and factors governing the total content and mobilization in soils. In *Vanadium in Soils and Plants* (pp. 1-32). CRC Press.
2. Zhang, B., Zhang, H., He, J., Zhou, S., Dong, H., Rinklebe, J. and Ok, Y.S., 2023. Vanadium in the environment: biogeochemistry and bioremediation. *Environmental science & technology*, 57(39), pp.14770-14786.
3. Banik, K., 2025. 8 Role of Vanadium Compounds on Human Health. *Trace Metals Selenium, Chromium and Vanadium: Chemistry, Biology and Human Health*, p.169.
4. Simandl, G.J. and Paradis, S., 2022. Vanadium as a critical material: economic geology with emphasis on market and the main deposit types. *Applied Earth Science*, 131(4), pp.218-236.
5. Sharfalddin, A.A., Al-Younis, I.M., Mohammed, H.A., Dhahri, M., Mouffouk, F., Abu Ali, H., Anwar, M.J., Qureshi, K.A., Hussien, M.A., Alghrably, M. and Jaremko, M., 2022. Therapeutic properties of vanadium complexes. *Inorganics*, 10(12), p.244.
6. Stachowicz, K., 2025. Vanadium—good or bad—The role of vanadium in the central nervous system disorders, potential therapeutic targets and its toxicity. *Toxicology Letters*, 410, pp.67-75.
7. Macías-Camacho, T.O. and Sánchez-Rodríguez, M.A., 2026. A systematic review of the effects of vanadium exposure on the health of human populations. *Critical Reviews in Toxicology*, 56(6), pp.389-408.
8. Arora, T., Agnihotri, N. and Azam, M., 2026. Vanadium's journey from essential trace metal to emerging environmental pollutant in the Anthropocene era. *Turkish Journal of Chemistry*, 50(2), pp.112-132.
9. Yang, J., Wang, Y., Gao, X., Zuo, R., Song, L., Jin, C., Wang, J. and Teng, Y., 2022. Vanadium: a review of different extraction methods to evaluate bioavailability and speciation. *Minerals*, 12(5), p.642.

10. Kumar, A., Kumar, V., THAKUR, M., SHARMA, A., RADZIEMSKA, M. and KUMAR, R., 2026. Vanadium in the Environment: Biogeochemical cycling, bioavailability, speciation and detoxification mechanisms. *Pedosphere*.
11. Dinda, R., Garribba, E., Sanna, D., Crans, D.C. and Costa Pessoa, J., 2025. Hydrolysis, ligand exchange, and redox properties of vanadium compounds: implications of solution transformation on biological, therapeutic, and environmental applications. *Chemical Reviews*, 125(3), pp.1468-1603.
12. Hu, P., Hu, P., Vu, T.D., Li, M., Wang, S., Ke, Y., Zeng, X., Mai, L. and Long, Y., 2023. Vanadium oxide: phase diagrams, structures, synthesis, and applications. *Chemical Reviews*, 123(8), p.4353.
13. Jones, G.R., Wang, H.S., Parkatzidis, K., Whitfield, R., Truong, N.P. and Anastasaki, A., 2023. Reversed controlled polymerization (RCP): depolymerization from well-defined polymers to monomers. *Journal of the American Chemical Society*, 145(18), p.9898.
14. Saran, R., 2022. *Analytical Techniques for Trace Elements in Geochemical Exploration*. Royal Society of Chemistry.
15. Ghosh, S. and Nandi, S., 2024. A comprehensive review on UV-visible spectroscopy and its application. *International Journal of All Research Education and Scientific Methods*, 12(1), pp.1501-1507.
16. Vogt, C., Wondergem, C.S. and Weckhuysen, B.M., 2023. Ultraviolet-visible (UV-Vis) spectroscopy. In *Springer handbook of advanced catalyst characterization* (pp. 237-264). Cham: Springer International Publishing.
17. Wu, R., Tian, M., Shu, C., Zhou, C. and Guan, W., 2022. Determination of the critical micelle concentration of surfactants using fluorescence strategies. *Soft Matter*, 18(47), pp.8920-8930.
18. Alamuoye, A.E., Emmanuel, S.A., Izuagie, T., Abodunrin, T., Mamman, S. and Aliyu, H.D., 2026. nComplexes of Crotonaldehyde and N-Benzaldehyde salicylhydrazones with some transition metals and their antimicrobial studies.
19. Patel, M.M. and Shah, M.C., 2022. Review on Spectrophotometric Method for formation of Metal Complexes of Hydrazone Derivatives. *YMER*, pp.2942-2964.
20. Khamees, L.A., Abdul-Majeed, G.H. and Alhaleem, A.A., 2026. Comparative assessment of SDBS, SLS, alumina nanoparticles, and kerosene-based systems for the selective removal of vanadium, nickel, and sulfur from crude oil. *Energy, Ecology and Environment*, 11(1), pp.39-65.