RASĀYAN *J. Chem.*
Vol. 19 | No. 4 | 2361-2370 | October-December | 2026
ISSN: 0974-1496 | e-ISSN: 0976-0083 | CODEN: RJCABP
http://www.rasayanjournal.com
http://www.rasayanjournal.co.in

# ECO-FRIENDLY EXTRACTION, SEPARATION AND SPECTROPHOTOMETRIC DETERMINATION OF BISMUTH(III) USING HNBHC FOR SUSTAINABLE ENVIRONMENTAL MONITORING

**P. N. Khaladkar[1], Y. R. Talekar[2], D.D. Agarkar[3], S. D. Bhumkar[2], S. S. Gholap[4], S. R. Kuchekar[5], and R. B. Gaikar[1]✉**

[1]Research Centre, Department of Chemistry, Padmashri Vikhe Patil College, Pravaranagar, Maharashtra, India
[2]Department of Chemistry, Arts, Commerce, Science and BCS College, Ashvi, Maharashtra, India
[3]Department of Chemistry, Arts, Commerce, Science College, Satral, Maharashtra, India
[4]Arts, Science and Commerce College, Rahata, Maharashtra, India
[5]PMT's Arts, Commerce & Science College, Shevgaon, Maharashtra, India
✉Corresponding author: rajugaikar@gmail.com

**ABSTRACT**

Bismuth(III) compounds have attracted considerable attention owing to their broad spectrum of biological activities, therapeutic efficacy, and relatively low toxicity. Among their well-established medical applications, Bi(III) complexes exhibit significant antimicrobial properties and are extensively employed in the treatment of *Helicobacter pylori*-associated peptic ulcers and diarrheal diseases. 2-(3-hydroxy-4-nitrobenzylidene)hydrazine-1-carbothioamide (HNBHC) was found to be an immense complexing agent. The current research focuses on extraction, separation, and spectrophotometric determination of Bi(III) from a real sample. The reagent present exhibited a yellow-colored Bi(III) complex with HNBHC. The complex was further quantitatively extracted in chloroform under acidic conditions. The maximum absorbance of Bi(III)- HNBHC was recorded at 435 nm. The metal – ligand stoichiometry was found as 1:1 and followed Beer's law over the wavelength-concentration range 10-60 µg $mL^{-1}$. The molar absorptivity and the Sandell's sensitivity were determined as 2.911 × 10^3 L $mol^{-1}$ $cm^{-1}$ and 0.0717 µg $cm^{-2}$, respectively. The scope of the present study was extended for the mutual separation of Bi (III), Pb (II) and Ni (II). The present protocol was found to be suitable for quantitative and qualitative determination of Bi(III) from various synthetic and pharmaceutical samples and sustains the environment. The present study helps to achieve sustainable development goals like good health and well-being, as bismuth is a key ingredient in gastrointestinal medicines.

**Keywords**: Bismuth(III), HNBHC, spectrophotometric method, pharmaceutical sample, sequential separation.
RASĀYAN *J. Chem.*, Vol. 19, No.4, 2026

## INTRODUCTION

Bismuth is a relatively rare element compared to many other naturally occurring elements. It occurs in the Earth's crust at extremely low abundance, constituting approximately 0.0002 % by weight.[1,2,3] It is widely used as a catalyst in the manufacture of acrylic fibers and also plays a vital role in the production of malleable iron.[4] In metallurgy, bismuth is incorporated into various alloys and metallurgical additives to improve material performance and processing characteristics; several alloys and metallurgical additives together with their uses in photochromic devices.[5] These alloys are frequently used in specific shut-off mechanisms in fusible parts of automatic sprinkler systems.[6] Recent studies have also demonstrated that bismuth-based semiconductors possess excellent photocatalytic performance, particularly in the reduction of carbon dioxide ($CO_2$ ) reactions and the destruction of organic pollutants when exposed to visible light. These advanced applications are largely attributed to the unique band structures and optical responses of bismuth-containing compounds, which enhance their efficiency in photocatalytic and optoelectronic processes.[7] They are commonly incorporated into products such as creams and hair dyes,


This work is licensed under a CC BY 4.0 license.

where they improve texture, appearance, and overall product performance.[8] Historically, bismuth preparations have been used in the treatment of syphilis and in managing gastrointestinal disorders such as colitis, diarrhoea, and peptic ulcers. They have also shown potential in the treatment of hypertension and various microbial and parasitic infections.[9] Bismuth-based compounds exhibit strong antimicrobial properties and are particularly effective against infections caused by *Helicobacter pylori*, a major causative agent of gastric ulcers and related gastrointestinal diseases.[10,11] In addition, certain bismuth complexes demonstrate significant antileishmanial activity, highlighting their potential in antiparasitic therapy.[12] Furthermore, Bi(III) complexes are known to exhibit diverse pharmacological properties, including antibacterial, antiacid, antiseptic, antiulcer, anti-HIV, and radiotherapeutic activities, making them important candidates for the development of modern therapeutic agents.[13,14] Although bismuth compounds have several industrial and medical applications, excessive exposure to bismuth may produce toxic effects in humans. Prolonged or high-level exposure has been associated with adverse health conditions such as nephropathy, osteoarthropathy, and hepatitis.[15] Therefore, careful monitoring and controlled use of bismuth-containing compounds are essential to minimize potential toxicological risks. Bismuth can be determined in a variety of different ways. The following analytical methods have been reported for the determination of bismuth: hydride generation inductively coupled plasma atomic emission spectrometry (ICP-AES), electrothermal vaporization inductively coupled plasma mass spectrometry (ICP-MS), atomic absorption spectrometry (AAS), electrothermal atomic absorption spectrometry (ET-AAS), X-ray fluorescence spectrophotometry (XFS), hydride generation atomic absorption spectrometry (AAS), flame atomic absorption spectrometry (FAAS), potentiometric stripping analysis (PSA), anodic stripping voltammetry (ASV), and cathodic stripping voltammetry (CSV).[15,16] Some authors have reported on the extractive, separation and spectrophotometric determination of Bi (III) using variety of reagents such as Alizarin red S and cetylpyridinium chloride[4], Pyrocatechol violet[13], 5-(2′-bromophenylazo)-6-hydroxypyrimidine-2,4-dione[17], N-m-tolyl-p-chlorobenzohydroxamic acid[18], Arsenazo (III)[19], Molten naphthalene[20], 1-(4'-bromophenyl)-4.4.6-trimethyl-(1H.4H)-pyrimidine-2- thiol[21], Bromo pyrogallol red[22], Pyridine-2-carboxaldehyde 2-hydroxybenzoylhydrazone[23], 1-amino-4,4,6-trimethyl (1H,4H) pyrimidine-2-thiol[24], Sodium hexamethyleneiminocarbodithioate[25], Cyanex 301[26], Pyrocatechol Violet and tridodecylethylammonium bromide[27], 4-(4′-chlorobenzylideneimino)-3-methyl-5-mercapto-1,2,4-triazole[28], 4-(2-pyridylazo) resorcinol.[29] The reported analytical methods have limitations such as lack of sensitivity, narrow Beer's law range, and limited application. These shortcomings emphasize the need for the development of a sensitive, simple and discriminating extractive spectrophotometric way for the determination of Bi(III) in a wide variety of matrices. The present study reports a simple, rapid, and selective extractive spectrophotometric method for the determination of Bi(III) employing 2-(3-hydroxy-4-nitrobenzylidene)hydrazine-1-carbothioamide (HNBHC) as a chromogenic reagent. In an acidic medium, HNBHC readily forms a stable complex with Bi(III), which is rapidly extracted into chloroform within one minute for quantitative analysis. The proposed analytical protocol supports SDG-3 by enabling the reliable quantitative determination of bismuth(III) from pharmaceutical products. The study also helps to achieve SDG-9 through the development of innovative and cost-effective analytical methodology and SDG-12 by promoting efficient quality control and sustainable analytical practices.

## EXPERIMENTAL

### Apparatus

Measurements were done using a dual-ray UV-visible (Model 2202) equipped with matched 1 cm quartz cells. Sample weighing was performed using a Contech electronic balance model CA-123. Before use, all glassware was thoroughly cleaned by rinsing with dil. $HNO_3$ followed by washing with soap solution and distilled water, and subsequently dried and calibrated.

### Synthesis of 2-(3-hydroxy-4-nitrobenzylidene)hydrazine-1-carbothioamide (HNBHC)

2-(3-hydroxy-4-nitrobenzylidene)hydrazine-1-carbothioamide was prepared using a modified procedure of the literature.[30,31] A solution of 3-hydroxy-4-nitrobenzaldehyde (0.33 g, 0.002 mmol) in ethanol (10 mL) was added dropwise to a stirred mixture of thiosemicarbazide (0.18 g, 0.002 mmol) in 40 mL of distilled water containing glacial acetic acid (2 mL). The resulting reaction mixture was refluxed for 12

hrs, and was allowed to cool to room temperature, resulting in the formation of a yellow crystalline solid. (M.P.-310$^0$C).The 0.24 gm of 2-(3-hydroxy-4-nitrobenzylidene)hydrazine-1-carbothioamide was quantitatively transferred to a 100 mL calibrated flask with DMF to prepare a 0.01 mol $L^{-1}$ stock solution of the reagent.

**Preparation of Standard Bi(III) Solution**

A standard stock solution of Bi(III) with a concentration of 100 µg $mL^{-1}$ was prepared by dissolving 0.023 g of bismuth nitrate pentahydrate in distilled water. The resulting solution was quantitatively transferred to obtain the desired concentration of the Bi(III) stock solution.

**Recommended Procedure**

An aliquot containing 60 µg of Bi(III) solution, 0.012 $mol^{-1}$ 2-(3-hydroxy-4-nitrobenzylidene)hydrazine-1-carbothioamide (HNBHC) in DMF, and the appropriate volume of perchloric acid solution (1.2 mol $L^{-1}$) were added into a standard volumetric flask and equilibrated with 10 mL of chloroform. The chloroform layer of the Bi(III)- HNBHC complex was separated into a dry beaker after phase separation. The moisture present in the organic phase was eliminated by treatment with 1.0 g An. sodium sulphate. The dried organic extract was subsequently transferred into a 10 mL calibrated volumetric flask with chloroform. Absorbance of the Bi(III)- HNBHC at 435 nm against a blank under identical experimental conditions.

## RESULTS AND DISCUSSION

**Absorption Spectra**

At 435 nm, the maximum absorbance of the Bi(III)-HNBHC complex is observed, and at this wavelength, the reagent blank does not show any absorption (Fig.-1). An overview of the physicochemical characteristics of the Bi(III)- HNBHC complex is given in Table-1.

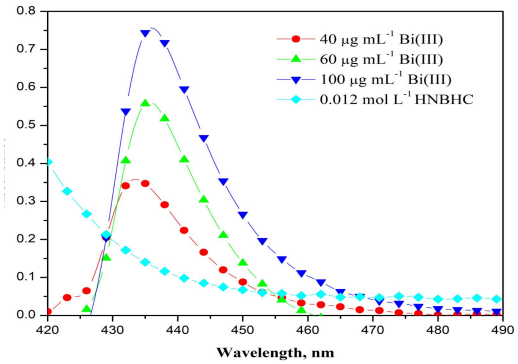



Fig.-1: Absorption Spectra of Bi(III)– HNBHC Complex (λmax: 435 nm)

Table-1: Spectral and Physicochemical Characteristics of Bi(III)–HNBHC Complex

| Characteristic | Parameters |
|---|---|
| Perchloric acid conc. | 1.2 mol $L^{-1}$ |
| Reagent concentration | 0.012 mol $L^{-1}$ |
| Equilibration time | 1 min |
| Extraction solvent | Chloroform |
| λ max | 435 nm |
| Molar absorptivity | 2.911 x $10^3$ L $mol^{-1}$ $cm^{-1}$ |
| Sandell's sensitivity | 0.0717 µg $cm^{-2}$ |
| Beer's law range | 10-60 µg $mL^{-1}$ |
| Ringbom's optimum range | 25-60 µg $mL^{-1}$ |
| Limit of detection | 0.823 µg $mL^{-1}$ |
| Relative standard deviation | 0.56% |
| Stoichiometry of the complex | 1:1 Bi(III): HNBHC |
| Stability of complex | >48 hrs |
| Correlation coefficient | 0.99 |

**Effect of Acid Concentration**

The influence of acidity on complex formation was investigated by varying the concentration of perchloric acid within the range of 0.2 to 1.8 mol $L^{-1}$. Quantitative complex formation and maximum extraction efficiency of Bi(III)–HNBHC complex were achieved at the optimum perchloric acid concentration of 1.2 mol $L^{-1}$. The role of perchloric acid is the distribution of metal ion between phases, thereby promoting complex formation and enhancing the extraction efficiency (Fig.-2).

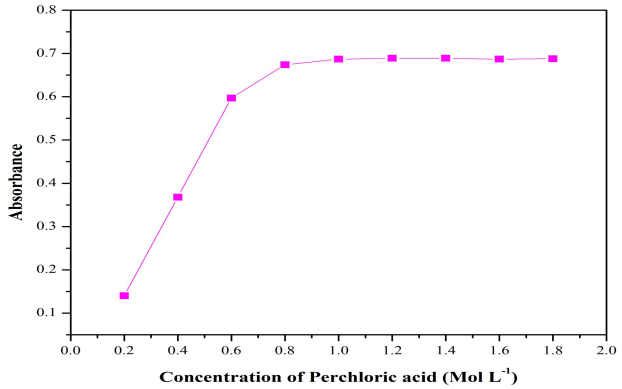



Fig.-2: Effect of Perchloric Acid Concentration

**Effect of Reagent Concentration**

The formation of the Bi(III)-HNBHC complex was evaluated by varying the HNBHC concentration in chloroform over the range of 0.002 to 0.020 mol $L^{-1}$. The absorbance of the extracted complex was subsequently measured under optimized experimental conditions using the proposed method.

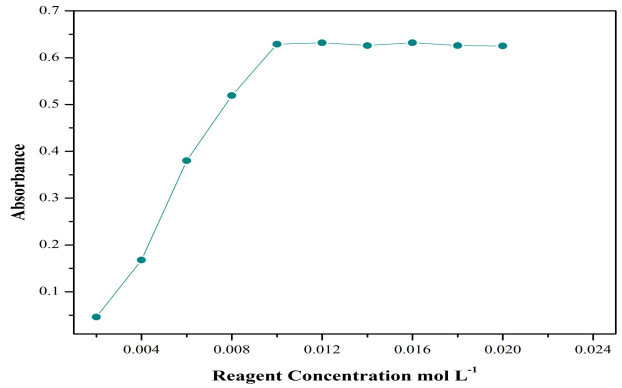



Fig.-3: Effect of Reagent concentration

The results demonstrated that a reagent concentration of 0.012 mol $L^{-1}$ was sufficient to ensure quantitative formation of the Bi(III)-HNBHC complex. Furthermore, the use of excess reagent was unnecessary and did not adversely affect the extraction process (Fig.-3).

**Effect of Extraction Solvents**

Different organic solvents were used for quantitative extraction of the complex, several solvents, including n-butanol, chloroform, toluene, benzene, ethyl acetate and cyclohexanone as possible extraction media. Among the solvents tested, chloroform exhibited the highest absorbance for the extracted Bi(III)-HNBHC complex at 435 nm, indicating its superior extraction efficiency. Therefore, chloroform was selected as the preferred solvent for subsequent extraction studies (Fig.-4).

**Analytical Figures of Merit**

Beer's law, as demonstrated by the calibration plot (Fig.-5). The analytical performance of the proposed method was further assessed from calibration data, which revealed a Sandell's sensitivity of 0.0717 µg $cm^{-2}$ and Molar absorptivity of 2.911 x $10^3$ L $mol^{-1}$ $cm^{-1}$.

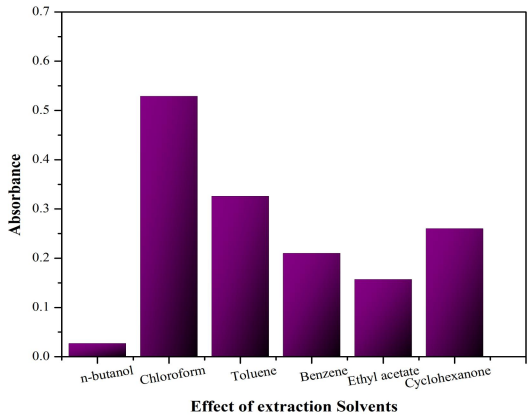



Fig.-4: Effect of Extraction Solvents

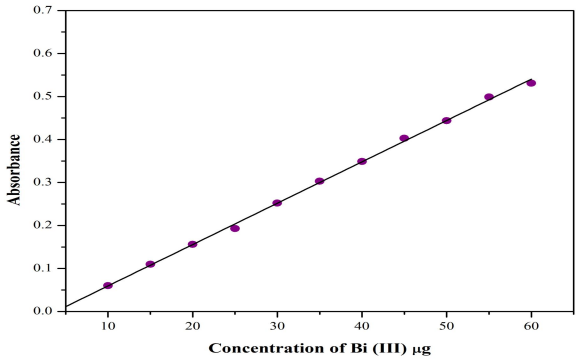



Fig.-5: Beer's Law Range for Bi(III)– HNBHC Complex

The correlation coefficient ($R^2$) of the Bi(III)- HNBHC complex was found to be 0.9990, demonstrating a high level of linearity.

The slope and intercept of the linear regression analysis were 0.00962 and -0.03676, respectively. Thus, it is possible to quantify Bi(III) in samples with the help of the equation y = 0.00962x-0.03676. The rectilinear section, which encompassed intermediate absorbance values of 25-60 µg $ml^{-1}$ was found to be the sigmoidal shape of the plot of Ringbom's.

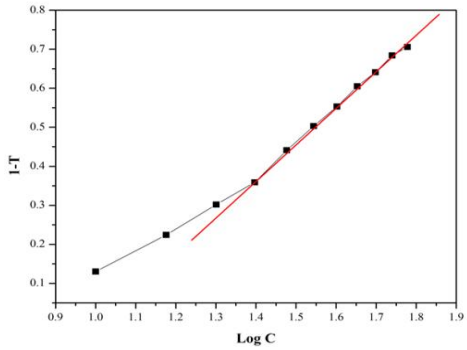



Fig.-6: Ringbom's Plot of Bi(III)– HNBHC Complex

The best concentration range was the graph of the logarithm of Bismuth(III) concentration C, versus (1-T), (Fig.-6).

**Stoichiometry of Bi (III)– HNBHC Complex**

The Job's variation technique was used to establish the stoichiometry of the Bi(III)- HNBHC complex. This was done by plotting the absorbance versus the mole fraction of the metal ion, which is determined as the ratio of the concentration of the metal to the concentration of the total metal and the ligand (Fig.-

7**)**.The complex's composition was determined utilizing the mole ratio method, in which the absorbance was determined as a function of the metal-to-ligand concentration ratio.

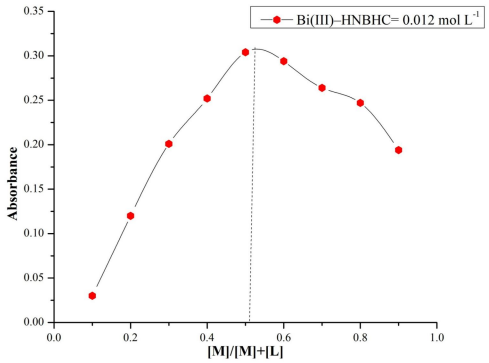



Fig.-7: Job's Continuous Variation Method for Bi(III)– HNBHC Complex

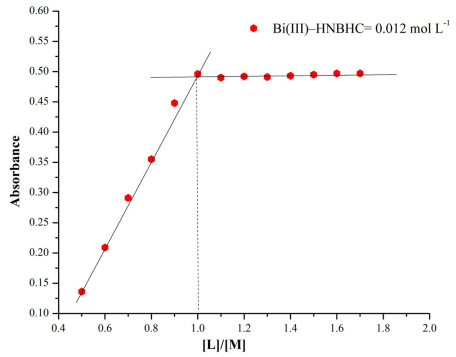



Fig.-8: Mole Ratio Plot for Bi(III)– HNBHC Complex

The result is shown in Fig.-8. Based on the findings from both approaches, the stoichiometric ratio of metal to ligand in the formed complex was confirmed to be 1:1.

## Interference Study

The selectivity of the proposed method was checked by testing different foreign ions such as Ba (II), Al (III), Ca (II), Cd (II), Ce (IV), Co (II), Cr (III), Cu (II), Mg (II), Mn (II), Mo (VI), Ni (II), Sn (II), Sr (III), Zn (II), Pb(II), Bromide, Chloride, Fluoride, Iodide, Nitrate, Sulphate, Thiocyanate, Oxalate, Acetate. The tolerance limit of each interfering ion was determined as the concentration that produced no more than a ±2% change in the absorbance of the Bi (III)-HNBHC complex. The interference from Mn(II), Mo(VI), Sn(II), Sr(II) and Cd(II) ions was effectively eliminated by EDTA as a masking agent. These results demonstrate the satisfactory selectivity of the developed procedure for the determination of Bi(III) in the presence of commonly associated ions.

### Extraction, Separation and Determination of Bi(III) from Binary Synthetic Mixtures

Binary synthetic mixtures were examined using the proposed approach to evaluate its applicability for the extraction, in the presence of various interfering metal ions including Ni (II), Cu (II), Mg (II), Co (II), and Pb (II). The number of repetitions (n) was 4. Bismuth (III) was separated from other related metal ions using the proposed approach. After being extracted in chloroform, the bismuth(III)-HNBHC complex was found at 435 nm. Following the quantitative separation of Bi(III), the aqueous phase containing the additional related metal ions was evaporated to dryness. After cooling and dissolving the residue containing extra metal ions was dissolved and detected spectrophotometrically using established methods[32] (Table-2).

**Extraction, Separation and Determination of Bi (III) from Ternary Synthetic Mixtures**

60 µg of Bi(III) were used to evaluate the influence of foreign metal ions on the spectrophotometric determination of the Bi(III)-HNBHC complex. Different metal ions were added in varying amounts to assess potential interference during complex formation and spectrophotometric measurement. The acidity of the solution was maintained at 1.2 mol $L^{-1}$ with perchloric acid to ensure suitable conditions for stable complex formation. Under these conditions, the extracted Bi(III)– HNBHC complex was recorded at 435 nm. The result confirms the presence of commonly occurring coexisting ions in complex sample matrices. (Table-3) reports the results.

Table-2: Extraction, Separation and Determination of Bi(III) from Binary Synthetic Mixtures

| Metal Ion | Amount Taken (µg) | Recovery[a] (%) | RSD (%) | Chromogenic Ligand | Ref. |
|---|---|---|---|---|---|
| Bi (III) | 60 | 99.28 | 0.59 | -- | -- |
| Ni (II) | 100 | 98.91 | 0.22 | DMG | 32 |
| Bi (III) | 60 | 99.28 | 0.39 | -- | -- |
| Cu (II) | 50 | 98.77 | 0.90 | Dithiocarbamate | 32 |
| Bi (III) | 60 | 99.32 | 0.56 | -- | -- |
| Mg (II) | 100 | 97.78 | 0.64 | Titan Yellow | 32 |
| Bi (III) | 60 | 99.01 | 0.60 | -- | -- |
| Co (II) | 75 | 99.43 | 0.57 | Nitroso- R- Salt | 32 |
| Bi (III) | 60 | 98.74 | 0.67 | -- | -- |
| Pb (II) | 50 | 99.33 | 0.48 | Dithizone | 32 |

Bismuth(III): 60 µg $mL^{-1}$, $HClO_4$: 1.2 mol $L^{-1}$, HNBHC: 0.012 mol $L^{-1}$, λmax: 435 nm
a: Average of four determinations

Table-3: Extraction, Separation and Determination of Bi(III) from Ternary Synthetic Mixtures

| Composition (µg) | RSD (%) | Recovery[a] (%) |
|---|---|---|
| Bi(III) 60; Co (II)50; Mg (II)50 | 0.38 | 99.64 |
| Bi (III) 60; Ni (II)70; Co (II)50 | 0.49 | 99.28 |
| Bi (III) 60; Mg (II)50; Ni (II)70 | 0.43 | 98.65 |
| Bi (III) 60; Cu (II)25; Ni (II)70 | 0.77 | 99.32 |
| Bi (III) 60; Pb (II)50; Mg (II)50 | 0.75 | 99.46 |

Bismuth (III): 60 µg $mL^{-1}$, $HClO_4$: 1.2 mol $L^{-1}$, HNBHC: 0.012 mol $L^{-1}$, λmax: 435 nm
a: Average of four determinations

**Extraction, Separation and Determination of Bi(III) from Synthetic Alloys**

By using the recommended method to extract Bi(III) from synthetic mixtures that correspond to alloys, the method validity was confirmed. The compositions had been prepared in the laboratory of Wood metal alloy, Newtons alloy, Bismuth-Cadmium alloy, and Rose metal alloy, separation and determination Bi(III), and the analytical results obtained were corresponding amount of Bi(III) taken.

Table-4: Extraction, Separation and Determination of Bi (III) from Synthetic Alloys

| Composition of alloy | Amount taken (µg) | Amount found (µg) | RSD (%) | Recovery[a] (%) |
|---|---|---|---|---|
| Wood metal alloy | 60 | 59.78 | 0.79 | 99.64 |
| Newton's alloy<br>Bi 50% + Pb 31.2% + Sn 18.8% | 60 | 59.56 | 0.61 | 99.28 |
| Bismuth- Cadmium alloy<br>Bi 60% + Cd 40% | 60 | 59.13 | 0.79 | 98.56 |
| Rose metal alloy<br>Bi 50% + Pb 25% + Sn 25% | 60 | 59.56 | 0.81 | 99.28 |

Bismuth (III): 60 µg $mL^{-1}$, $HClO_4$: 1.2 mol $L^{-1}$, HNBHC: 0.012 mol $L^{-1}$, λmax: 435 nm
a: Average of four determinations

**Extraction, Separation and Determination of Bismuth (III) from Pharmaceutical Sample**

Pharmaceutical sample: Bismuthum subnitricum tablets and Bistas.

The sample (1 tablet) was accurately weighed and finely powdered. A beaker was used to transfer the powdered sample and dissolve it in 10 mL of distilled water. The mixture was subsequently filtered to remove the insoluble materials, as per the proposed procedure. Table-5 gives the results.

Table-5: Extraction, Separation and Determination of Bi (III) from Pharmaceutical Samples

| Product Name and manufacturer | Composition | Certified value of Bi(III), mg | Found by proposed method, mg | RSD (%) | Recovery[a] (%) |
|---|---|---|---|---|---|
| Bismuthum Subnitricum (Dr. Willmar Schwabe India Pvt. Ltd. (Phase III), Noida, 201304) | Bismuth Subnitrate | 0.00018 | 0.00017 | 0.70 | 99.10 |
| Bistas (Waterley Pharmaceutical Pvt. Ltd., Hasmathpet, Secunderabad, Telangana-500009, India) | Colloidal Bismuth Subcitrate | 63 | 62.8 | 0.84 | 99.82 |

a: Average of four determinations

**Sequential Extraction of Bismuth (III), Lead (II) and Nickel (II)**

Which would isolate, dissolve and measure Bismuth (III), Lead (II) and Nickel (II) as shown in Scheme-1. The separation of bismuth in chloroform was done by means of 0.012 mol $L^{-1}$ HNBHC in the presence of 1.2 mol $L^{-1}$ perchloric acid as an acidic medium. At the same time, lead (II) and Nickel (II) were evaporated from the aqueous layer.

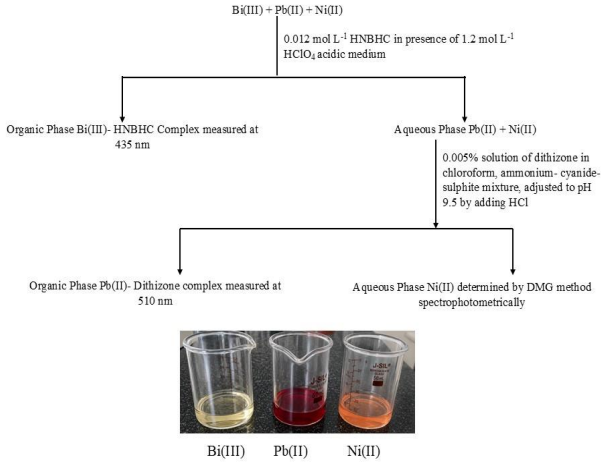



Fig.-9: Sequential Extraction of Bismuth (III), Lead (II) and Nickel (II)

Table-6: Sequential Extraction of Bismuth (III), Lead (II) and Nickel (II)

| Mixture | Amount taken (µg) | Chromogenic ligand | RSD (%) | Recovery[a] (%) |
|---|---|---|---|---|
| Bi (III) + Pb (II) + Ni (II) | Bi (60) | HNBHC | 0.58 | 98.92 |
| | Pb (50) | Dithizone | 0.91 | 99.46 |
| | Ni (100) | DMG | 0.85 | 99.84 |

a: Average of three determinations

To add 0.005% solution of dithizone in $CHCl_3$ was added, and the ammonia-cyanide-sulphite mixture was adjusted to a pH of 9.5 with the addition of HCl. Lead (II) extraction was completed by mixing the mixture with 10 mL of water, once more extracted in chloroform, and Pb(II)- Dithizone was 510 nm.[32] Nickel(II) in aqueous solution. Nickel(II) was ascertained with the help of a spectrophotometer[32] after diluting the residue with 10 mL of distilled water.

## CONCLUSION

The present procedure for the determination of Bi(III) is compared to other reported spectrophotometric methods. 2-(3-hydroxy-4-nitrobenzylidene)hydrazine-1-carbothioamide has also been shown to be an efficient spectrophotometric determination of Bi(III). The proposed reagent is sensitive, can be

determined easily, and is cost-effective. To ensure a successful application of the procedure, it is advisable to use a low concentration of the reagent. The application of Bi(III) was achieved by the developed methodology to isolate and quantify Bi (III) in Synthetic samples like binary mixtures, ternary mixtures, and synthetic alloys, and pharmaceutical samples. Additionally, this research supports SDG-3 by allowing reliable analysis of bismuth-containing pharmaceutical products, SDG-9 through the development of an innovative and efficient analytical methodology, and SDG-12 by promoting accurate quality control and the effective use of pharmaceutical applications.

## ACKNOWLEDGMENTS

The authors are grateful to Savitribai Phule Pune University and the Management and Principal of Padmashri Vikhe Patil College of Arts, Science and Commerce, Pravaranagar, in relation to provision of the necessary facilities they need.

## CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

## AUTHOR CONTRIBUTIONS

The present work is related to *SDG-9: Industry, Innovation, and Infrastructure*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

P. N. Khaladkar https://orcid.org/0009-0009-6713-5624
Y. R. Talekar https://orcid.org/0000-0002-9622-4425
D.D. Agarkar https://orcid.org/0000-0001-9297-6227
S.D. Bhumkar https://orcid.org/0009-0008-3595-7597
S. S. Gholap https://orcid.org/0000-0002-0883-3889
S.R. Kuchekar https://orcid.org/0000/0002/6653/4828
R.B. Gaikar https://orcid.org/0000-0001-6573-3334

**Open Access:** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.
**Cite this article as:** P. N. Khaladkar *et al.*, *Rasayan J. Chem.*, 19(4), 2361-2370(2026), https://doi.org/10.31788/RJC.2026.1949998

## REFERENCES

1. P. Jia, J. Pang, Yong Chu, Shanhe Li, Wenjuan Li, M. Jiang, F. Yang, *Journal of Molecular Structure,* **1318**, 139389(2024), https://doi.org/10.1016/j.molstruc.2024.139389
2. I. M. Marzano, M.S. Franco, P.P. Silva, R. Augusti, G.C. Santos, N. G. Fernandes, M. Bucciarelli-Rodriguez, E. Chartone-Souza and E. C. Pereira-Maia, *Molecules*, **18**, 1464(2013)
3. S. Andleeb, I. ud Din, M. Khawar Rauf, S. S. Azam, I. ul Haq, M. N. Tahir, S. Ahmad, *Applied Organometallic Chemistry*, **e5061**, 1(2019), https://doi.org/10.1002/aoc.5061
4. S. A. Mohammed, M. Mohammed, *Rafidain Journal of Science*, **24(5),** 52(2013), https://doi.org/10.33899/rjs.2013.78759
5. M. Chamsaz, M.H. Arbab-Zavar, M.M. Riazi and R. Takjoo, *Asian Journal of Chemistry*, **23(6),** 2441 (2011).
6. S. Abbas, I. ud Din, M. Mehmood, M. K. Rauf, S. S. Azam, I. ul Haq, M. N. Tahir, N. Parvaiz, *Journal of Molecular Structure*, **1230**, 129870(2021), https://doi.org/10.1016/j.molstruc.2021.129870
7. A. N. Terpilowska, M. Akhtar, G. Hussain, A. Piasecki, P. Blaszkiewicz, M. Tulinski, E. Wolarz, T. Karpinski, *Scientific Reports*, **15**, 21741(2025), https://doi.org/10.1038/s41598-025-05654-1
8. M. Marzano, D. Tomco, R. J. Staples, E. H. Lizarazo-Jaimes, D. Assis Gomes, M. Bucciarelli-Rodriguez, W. Guerra, P. de Souza, C. N. Verani, E. C. Pereira Maia, *Journal of Inorganic Biochemistry*, **222**, 111522(2021), https://doi.org/10.1016/j.jinorgbio.2021.111522

9. U. Dittes, E. Vogel, Bernhard K. Keppler, *Coordination Chemistry*, **163**, 345(1997), https://doi.org/10.1016/S0010-8545(97)00042-8
10. Satya, K. Hashmi, S, Gupta, P. Mishra, E. Veg, T, Khan, S. Joshi, *Engineering. Proceeding*, **37(1),** 48, (2025).
11. X. Liu, M. Xiao, L. Xu, Y. Miao, and R. Ouyang, *Journal of Nanoscience and Nanotechnology*, **16**, 6679(2016), https://doi.org/10.1166/jnn.2016.11371
12. Y. Yang, S. Zhou, R. Ouyang, Y. Yang, H. Tao, K. eng, X. Zhang, F. Xiong, N. Guo, T. Zong, P. Cao, Y. Li, and Y. Miao, *Chemical Pharmaceutical Bulletin,* **64**, 1539(2016), https://doi.org/10.1248/cpb.c15-00949.
13. E. S. Thanoon, K. M. Omer, *Journal of University of Anbar for Pure Science,* **13(1),** 16(2019), https://doi.org/10.37652/juaps.2022.171866
14. R. Dobrowolski, J. Dobrzyńska & B. Gawrońska, *Environmental Monitoring and Assessment*, **187**, 4125(2015), https://doi.org/10.1007/s10661-014-4125-7
15. P. Xia, Y. Song, Yu-Ze Liu, M. Long, C. Yang, X. Zhang and T. Zhang, *Journal of Materials Chemistry*, **12**, 1609 (2024).
16. D.Venkataramana Reddy and A. Varada Reddy, *E-Journal of Chemistry*, **7(4),** 1290(2010).
17. A. S. Amin, I. A. Zaafarany, *Journal of Taibah University for Science,***9(4)**,1(2015), http://dx.doi.org/doi:10.1016/j.jtusci.2015.01.003
18. Y. K. Agrawal an V. J. Bhatt, *Analyst*, **109**, 1287(1984), https://doi.org/10.1039/AN9840901287
19. S. A. Mohammad, M. M. Mohammed, *Baghdad Science Journal*, **10(3),** 986(2013), https://doi.org/10.21123/bsj.10.3.986-996
20. M. Satake, *Division of applied Science*, 135(1977).
21. G. B. kolekar, T. N. Lokhande, P. N. Bhosale, M. A Anuse, *Analytical Letters*, **31(13),** 2241(2006), https://doi.org/10.1080/00032719808005299
22. N. H. Shekho, E. S. Thunoon, *Rafidain Journal of Science,* **24(2),** 39(2013).
23. M. N. Bale, A. D. Sawant, H. Shaikh and D. J. Garole, *Asian Journal of Chemistry*, **29(6),** 1328 (2017), https://doi.org/10.14233/ajchem.2017.20489
24. S H Gaikwad, S V Mahamuni & M A Anuse, *Indian Journal of Chemical Technology*, **12**, 365 (2005).
25. S. D. Dhanavate, D. J. Garole and A. D. Sawant, *Journal of Materials and Environmental Science*, **6(2),** 519(2015).
26. Anant P. Argekar and A. K. Shetty, *Analyst*, **120**, 1819(1995).
27. S. Yoshio, S. Tokuo, S. Kaoru, *Bulletin of the Chemical Society of Japan*, **56(1),** 105(1983).
28. U. B. Barache, A. B. Shaikh, S. A. Deodware, P. C. Dhale, G. S. Kamble, T. N. Lokhande, S. H. Gaikwad, *Groundwater for Sustainable Development*, (2019), https://doi.org 10.1016/j.gsd.2019.100221
29. N. H. Shekho, E. S. Thunoon, *Baghdad Science Journal*, **10(3)**, Article 34(2013).
30. A. Abbasi, S. Geranmayeh, A. Naghi Taheri, H. Shahroosvand and M. Shabani, *E-Journal of Chemistry*, **7(S1),** S294(2010), https://doi.org/10.1155/2010/347576
31. M. Sivasankar Reddy, Y. Sarala, M. Jagadeesh, Samar K. Das and V. Reddy Ammi reddy, *Acta Crystallographica***, E70**, o846(2014).
32. E. B Sandell, Colorimetric determination of traces metals, *Interscience Publishers, Inc., New York*, 3rd edition (1959).

[RJC-9998/2026]