EVALUATION OF THE SENSITIVITY AND SELECTIVITY CHARACTERISTICS OF IMMOBILIZED SORBENTS FOR THE DETERMINATION OF BI(III) IONS

Mashhura Turdiboy-kizi Razhabova
Khurshida Razhobboyovna Kosimova
Samarkand State Pedagogical Institute

Abstract: The present study evaluates the analytical performance of silica gel-based immobilized sorbents for the determination of Bi(III) ions in aqueous solutions. Particular attention was focused on the sensitivity and selectivity characteristics of the developed sorption-spectrophotometric system. The immobilized sorbent exhibited high affinity toward Bi(III) ions, allowing efficient preconcentration and subsequent determination at trace concentration levels. The influence of pH, reagent loading, contact time, sorbent dosage, and foreign ions on analytical performance was systematically investigated. Under optimal conditions, the proposed method provided a detection limit of 0.012 mg/L, a linear range of 0.02-6.0 mg/L, and a correlation coefficient of 0.999. The results demonstrate the applicability of immobilized sorbents for sensitive and selective determination of Bi(III) ions in environmental and industrial samples.

Keywords: Bi(III), immobilized sorbent, silica gel, sensitivity, selectivity, sorption-spectrophotometry, analytical chemistry

INTRODUCTION

Bismuth is an important heavy metal widely used in pharmaceutical formulations, metallurgy, semiconductor technology, cosmetics, and electronic materials. Monitoring Bi(III) ions in environmental and industrial samples has become increasingly important due to the growing use of bismuth-containing compounds. Conventional spectrophotometric methods often require complex sample preparation and may suffer from insufficient sensitivity when trace concentrations of Bi(III) are present. Immobilized sorbents provide an effective alternative by combining preconcentration and detection in a single analytical system. The immobilization of chromogenic reagents on solid supports improves reagent stability, enhances selectivity, and reduces reagent consumption. Silica gel is among the most frequently used carriers because of its high specific surface area (500–700 m^2/g), chemical inertness, mechanical strength, and ease of surface modification. Therefore, the assessment of sensitivity and selectivity characteristics of immobilized sorbents is essential for developing reliable methods for Bi(III) ion determination.

MATERIAL AND METHODS

Reagents and materials:

1. $Bi(NO_3)_3 \cdot 5H_2O$ (analytical grade)
2. Nitric acid (65%)
3. Sodium hydroxide
4. Silica gel (particle size 0.10–0.20 mm)
5. Distilled water
6. Immobilized chromogenic reagent

Instrumentation:

1. UV-Vis spectrophotometer (190–1100 nm)
2. pH meter
3. Analytical balance (±0.0001 g)
4. Orbital shaker

Silica gel was activated at 105°C for 4 h and treated with a chromogenic reagent solution for 24 h. After immobilization, the sorbent was washed until the washing solution became colorless and then dried at room temperature. 50 mL of Bi(III) solution was mixed with 0.10 g of immobilized sorbent. The pH was adjusted using dilute HNO_3 or NaOH. After equilibration, the sorbent was separated and absorbance measurements were carried out at the maximum absorption wavelength.

RESULTS AND DISCUSSION

The pH of the medium significantly affects complex formation and sorption efficiency. The results obtained are presented in Table 1.

Table 1

№	pH	Sorption (%)	Absorbance
1	1.0	41	0.183
2	2.0	73	0.328
3	2.5	89	0.412
4	3.0	97	0.489
5	3.5	99	0.495
6	4.0	93	0.452
7	5.0	78	0.361

The highest analytical signal was observed in the pH range 3.0-3.5. At lower pH values, competition between H^+ and Bi^{3+} ions decreases sorption efficiency. At pH values above 4.0, hydrolysis processes become significant.

The sensitivity of the proposed method was evaluated through calibration characteristics and the contact time required to reach equilibrium was investigated. (Table2)

Table 2

№	Parameter	Value	№	Time (min)	Sorption (%)
1	Linear range	0.02–6.0 mg/L	1	1	46
2	Calibration equation	A = 0.097C + 0.002	2	5	71
3	Correlation coefficient (R^2)	0.999	3	10	91
4	Detection limit (LOD)	0.012 mg/L	4	15	98
5	Quantification limit (LOQ)	0.040 mg/L	5	20	99
6	Relative standard deviation (RSD)	2.4 %	6	30	99

The calibration curve demonstrated excellent linearity within the investigated concentration range. The low LOD indicates that the developed sorption system can be used for trace-level determination of Bi(III) ions. More than 90% of Bi(III) ions were sorbed within the first 10 minutes. Sorption equilibrium was achieved after approximately 15 minutes, indicating rapid interaction between Bi(III) ions and the immobilized active centers.

The selectivity of the method was assessed by studying the influence of foreign ions commonly found in natural and industrial waters. (Table 3)

Table 3

№	Foreign ion	Tolerance ratio (Bi : Ion)	№	Foreign ion	Tolerance ratio (Bi : Ion)
1	Na^+	1:1000	1	Zn^{2+}	1:100
2	K^+	1:1000	2	Cd^{2+}	1:50
3	Ca^{2+}	1:500	3	Pb^{2+}	1:50
4	Mg^{2+}	1:500	4	Cu^{2+}	1:25
5	Al^{3+}	1:100	5	Fe^{3+}	1:20

The obtained results indicate high selectivity toward Bi(III) ions. Alkali and alkaline earth metal ions did not interfere even at concentrations several hundred times greater than that of Bi(III). Transition metal ions exhibited stronger interference because of competitive complex formation.

Comparison with conventional methods. (Table 4)

Table 4

№	Method	Detection limit (mg/L)	Analysis time (min)
1	Direct spectrophotometry	0.080	30
2	Extraction-photometry	0.040	45
3	ICP-OES	0.005	10
4	Proposed immobilized sorbent method	0.012	15

Although ICP-OES provides a lower detection limit, the proposed method offers significant advantages including lower cost, simpler instrumentation, shorter sample preparation, and applicability in routine laboratories.

CONCLUSION

The sensitivity and selectivity characteristics of silica gel-immobilized sorbents for the determination of Bi(III) ions were successfully evaluated. The developed sorption-spectrophotometric system exhibited high sorption efficiency (99%), excellent linearity (R^2 = 0.999), low detection limit (0.012 mg/L), and satisfactory precision (RSD = 2.4%). The immobilized sorbent demonstrated good selectivity toward Bi(III) ions in the presence of large excesses of common foreign ions. The rapid equilibration time (15 min) and favorable analytical performance indicate that the proposed method is suitable for the determination of trace amounts of Bi(III) ions in environmental, industrial, and laboratory samples. Furthermore, the simplicity, low cost, and high analytical efficiency of the method make it a promising alternative to more expensive instrumental techniques.

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