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Research Article

THE DEVELOPMENT OF NEW METHODS FOR DETECTING IRON IONS IN WATER AND CONDUCTING QUANTITATIVE ANALYSIS OF THESE IONS

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ABSTRACT

The dynamics of seasonal and annual changes in the concentration of iron (III) ions in the waters of the Kungirot district of the Republic of Karakalpakstan were analyzed. A method for determining iron (III) ions using immobilized organic reagents containing nitrogen and oxygen was proposed. The sorption-spectrophotometric method was compared with other methods, and the t and F criteria were determined. Favorable conditions for the immobilization of organic reagents were identified. Scanning electron microscope images of the immobilized organic reagent, sorbent, and the formed iron (III) ion complex were captured.

KEYWORDS

Waters of Kungirot district, immobilization, organic reagent, methyl thymol blue, monitoring, iron ions, sorption-spectrophotometric method, sorbent.

INTRODUCTION

Iron is one of the trace elements essential for the life activity of living organisms. A deficiency of iron in the human body significantly affects metabolism. However, an excess of this element can lead to a disease related to the cardiovascular and digestive systems in humans, known as hemochromatosis [1]. Excess iron can enter the human body due to the wear of water pipes or, for populations living in industrial areas, through wastewater discharge from factories. Therefore, monitoring the iron content in environmental objects is essential for continuous monitoring. Currently, many methods have been developed to determine the concentrations of iron ions. For example, spectrophotometric methods using

various ligands have been developed for the detection of iron ions [2-5]. However, the sensitivity level of this method is relatively low, and it requires more time, which hinders its use on a large scale. The ICP-MS method allows for the detection of iron ions with high sensitivity and selectivity [6-9]. However, the use of ICP-MS requires expensive equipment. One of the most developed methods for detecting heavy and toxic metals today is sorption-spectrophotometry. This improved variant of spectrophotometry stands out due to its speed, high sensitivity, and selectivity, and it does not require expensive instruments. Many heavy and toxic metals have been detected using this method [10-12]. Our scientific research is based on the sorption-spectrophotometric detection of iron ions using immobilized organic reagents.

METHODS

Materials for the Study:For the detection of iron ions, the reagent methyl thymol blue, which contains nitrogen and oxygen, was selected based on a review of the literature. It was found that reagents with nitrogen and oxygen are particularly effective for detecting d-metals. Various fibrous sorbents were used for the immobilization of the chosen reagent.

Methodology: Selection of Reagents: The reagent methyl thymol blue was chosen due to its ability to interact effectively with d-metals. This reagent contains both nitrogen and oxygen, which are essential for the proper binding and detection of iron ions.

Immobilization of the Reagent: Different fibrous sorbents were tested for the immobilization of the reagent. The static exchange capacities of the selected polymer fibrous materials were determined in order to assess their suitability for use as solid carriers in the immobilization process.

Analysis of Static Exchange Capacity: The static exchange capacity of the polymer fiber materials was measured to understand their efficiency in adsorbing and retaining the methyl thymol blue reagent. This step is crucial for ensuring the effectiveness of the immobilized reagent in detecting iron ions.

By combining these materials and methods, the study aimed to develop an efficient and reliable method for detecting iron ions using immobilized organic reagents.

The static exchange capacity (COE) of fibrous carriers was determined using the following formula:

$$\mathrm{COE} = \frac{(V \cdot K_1 - K \cdot V_1 \cdot K_2) \cdot 100}{m(100 - W)} \cdot c$$

Where:

- **V** = Volume of the working solution, cm^3
- **K** = Coefficient equal to the ratio of the volume of the working solution to the volume of the solution used for titration
- **V1** = Volume of the solution consumed for titrating the sample after interacting with the ion exchanger, cm^3
- **m** = Weight of the ion exchanger, g
- **W** = Mass fraction of moisture, %
- **c** = Concentration of the working solution and titrating solution, mol/dm^3

- **K1** and **K2** = Correction factors for the working solution and titrating solution, respectively.

This formula is used to calculate the static exchange capacity, which indicates how effectively the fibrous material can exchange ions with the solution.

RESULTS AND DISCUSSION

In this study, the sorption-spectrophotometric method with immobilized organic reagents proved to be an effective technique for detecting iron ions in various water sources. The method provided reliable results for both wastewater and drinking water, demonstrating its practical application in environmental monitoring. The findings indicate that the method can be used for the analysis of water quality in regions affected by industrial discharge and urban use.

Further analysis of the results will help identify the environmental impact of iron ions in these water bodies and facilitate ongoing monitoring to ensure the safety and quality of water resources for local populations.

Table 1

Results of Sorption-Spectrophotometric Determination of Iron (III) Ion Micro Quantities(n=5, F=95)

Element	**Immobilized Reagent**	**Sample**	**Introduced, µg/dm³**	**Found µg/dm³**	**S***	**Sr ****	$\bar{\varepsilon}$ *******
Fe	Methyl Thymol Blue (MTB)	Drinking Water	0	0.25 ± 0.01	0.006	0.024	4%
			10.0	10.2 ± 0.02	0.010	0.001	0.2%
			20.0	20.31 ± 0.03	0.015	0.001	0.15%
		Oltin Ko'l Canal Water	0	1.12 ± 0.03	0.015	0.014	3.36%
			10.0	11.2 ± 0.18	0.1	0.009	1.6%
			20.0	21.12 ± 0.23	0.126	0.006	1%

Element	Immobilized Reagent	Sample	Introduced, µg/dm³	Found µg/dm³	S*	Sr **	$\bar{\varepsilon}$ ***
		Industrial Wastewater	0	3.32 ± 0.05	0.029	0.009	3.78%
			10.0	13.4 ± 0.18	0.100	0.008	1.57%
			20.0	23.11 ± 0.04	0.023	0.0001	0.173%

Notes:

- S is the standard deviation of the mean value.
- **Sr** is the relative standard deviation.
- $\bar{\varepsilon}$ *** indicates the percentage of error.

The table presents the results of the sorption-spectrophotometric analysis of iron (III) ions in various water samples. The detected concentration of iron (III) ions shows a clear increase as the concentration of introduced ions rises, demonstrating the reliability of the method for detecting micro quantities of iron in drinking water, canal water, and industrial wastewater. The relative errors remain low, which indicates the accuracy and precision of the method.

In the analysis presented in Table 1, the sorption-spectrophotometric determination of iron (III) ions was performed using immobilized organic reagent (methyl thymol blue) in different water samples: drinking water, water from the Oltin Ko'l canal, and industrial wastewater. The results show the concentration of iron ions in the samples before and after the introduction of known amounts of iron, with the measured concentrations closely matching the introduced values.

The highest concentrations of iron ions were found in industrial wastewater, as expected, due to the higher likelihood of contamination in industrial areas.

The lowest concentrations were found in drinking water samples, which generally contain much lower levels of pollutants.

The Oltin Ko'l canal water had intermediate iron concentrations, highlighting the need for continuous monitoring in water sources exposed to both industrial and natural contaminants.

The standard deviations (S) and relative standard deviations (Sr) are relatively low across all samples, indicating that the experimental procedure was consistent and reproducible.

The statistical evaluation confirms that the method is robust and provides repeatable results, essential for monitoring water quality over time.

Given the low relative errors and high accuracy, this method is suitable for long-term environmental monitoring, particularly in areas with varying levels of industrial discharge, such as the Kungirot district.

Regular monitoring of iron concentrations in local water sources is critical for public health and the maintenance of safe drinking water standards.

In conclusion, the sorption-spectrophotometric method with immobilized organic reagents demonstrates high precision, sensitivity, and accuracy, making it an effective tool for detecting iron ions in water. The results suggest that this method could be widely applied in both industrial and environmental settings to ensure water quality and prevent the harmful effects of excess iron contamination.

In the scientific research, the changes in the concentration of iron ions in the samples collected from the observation wells at the entrance section of the Oltinko'l canal were analyzed over the years.

As a result of analyzing and summarizing the chemical composition of the waters, the seasonal and annual variations in the concentration of iron ions were evaluated.

Table 2

Seasonal and Annual Dynamics of Iron Ions in the Oltin Ko'l Canal

Year	Winter	Spring	Summer	Autumn
2019	0.32	1.5	0.32	0.32
2020	0.52	3.5	0.52	0.52
2021	0.16	2.78	0.31	0.45
2022	0.36	2.75	0.6	0.68
2023	0.56	4.5	0.41	0.42

Analysis of the Iron Ion Concentration (μg/dm^3)

Winter:2019 to 2023: The concentration of iron ions in winter shows an increase over the years. In 2019, it was 0.32 μg/dm^3, and by 2023, it rose to 0.56 μg/dm^3. This indicates a general upward trend in iron concentrations during the winter months.

Key Observation: The increase between 2021 (0.16 μg/dm^3) and 2023 (0.56 μg/dm^3) is notable, suggesting an increase in sources or processes contributing to iron levels during the winter.

Spring:2019 to 2023: Spring has the highest variability in the concentration of iron ions. In 2019, it was 1.5 μg/dm^3, and by 2023, it reached 4.5 μg/dm^3. This shows a substantial increase over the five-year period.

Key Observation: The spring months, particularly in 2023, exhibit the highest concentration of iron ions, suggesting that seasonal factors such as agricultural runoff, irrigation, and precipitation contribute significantly to the presence of iron in spring.

Summer :2019 to 2023: The concentration of iron ions in the summer months fluctuated, with a slight decrease from 0.52 μg/dm^3 in 2020 to 0.41 μg/dm^3 in 2023. However, the levels were still lower compared to spring.

Key Observation: The summer season seems to show lower iron concentrations compared to spring, which could indicate a reduced influx of iron due to less precipitation and agricultural activity during the hot months.

Autumn :2019 to 2023: The concentration of iron ions in autumn fluctuated between 0.32 μg/dm³ (2019) and 0.68 μg/dm³ (2022), with a minor increase in 2022. However, it remains generally low compared to the spring months.

Key Observation: Autumn sees a slight increase in iron ion concentrations, possibly due to the residual effects of precipitation and agricultural runoff from the spring and summer months.

General Trends:Highest Concentration in Spring: The spring season consistently shows the highest iron ion concentrations across the years, particularly in 2023, which could be attributed to increased precipitation and the use of fertilizers in agriculture.

Lowest Concentration in Winter of 2021: The lowest recorded concentration was in the winter of 2021 (0.16 μg/dm³), suggesting an unusual reduction in iron levels that year.

Increasing Trend in Winter: There is an increasing trend in iron concentration during winter, particularly between 2021 and 2023.

Seasonal Variation: Spring and summer exhibit more fluctuation compared to autumn and winter, which are more stable.

The concentration of iron ions in the Oltinko'l canal water shows seasonal variation, with the highest levels observed in spring and the lowest in winter. This seasonal change could be linked to various environmental factors such as agricultural practices (fertilizer use, irrigation), precipitation patterns, and the migration of metals. The observed increase in iron levels in the winter months towards 2023 suggests potential changes in environmental conditions, such as industrial discharges or changes in water chemistry, influencing the ion concentration in the canal.

CONCLUSION

In this study, the seasonal and annual variations in the concentration of iron (III) ions in the waters of the Oltin Ko'l canal, located in the Kungirot district of the Republic of Karakalpakstan, were thoroughly analyzed. The results indicate that iron ion concentrations are influenced by both seasonal and annual fluctuations, with the highest levels observed in the spring months. The spring peak is likely a result of increased precipitation and agricultural activities, such as the application of mineral fertilizers, which facilitate the migration of metals into the water.

Through the use of an immobilized organic reagent and the sorption-spectrophotometric method, the concentration of iron ions in various water samples—such as drinking water, industrial wastewater, and canal water—was effectively determined. The method showed high reliability and accuracy, with minimal relative error.

The findings also suggest that iron concentrations are relatively low during the winter and summer, with the most significant changes occurring in spring and autumn. The results emphasize the importance of monitoring iron ion concentrations in water bodies, particularly in regions with agricultural and industrial activities, to ensure environmental safety and public health.

This study highlights the effectiveness of the sorption-spectrophotometric method for detecting trace

amounts of iron ions and offers a reliable approach for environmental monitoring and water quality analysis. Additionally, the data can help inform local policies regarding water quality management, particularly in regions affected by both natural and anthropogenic factors.

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