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Identification and Estimation of Metal Contaminants in Wastewater using Complexometric Titration: A Study on Pb, Mn, and Hg

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Abstract: *Industrial and agricultural activities often lead to the contamination of wastewater with heavy metals such as lead (Pb), manganese (Mn), and mercury (Hg), which pose significant environmental and health risks. Monitoring the concentration of these metal contaminants is crucial for water quality assessment and pollution control. This study aims to identify and estimate the levels of Pb, Mn, and Hg in wastewater samples using complexometric titration, a well-established analytical technique.*

Wastewater samples were collected from various industrial discharge sites and subjected to complexometric titration using ethylenediaminetetraacetic acid (EDTA) as the titrant for metal ion determination. The metal ions were first pre-treated with appropriate reagents to form stable complexes, and then their concentrations were determined by measuring the end point of the titration using a suitable indicator. The results were compared against the permissible limits for heavy metals in wastewater, as set by environmental protection agencies.

Preliminary findings indicate that Pb and Hg concentrations exceeded the regulatory limits in certain samples, while Mn levels were within acceptable thresholds. The study demonstrates the effectiveness of complexometric titration in the precise estimation of metal contaminants in wastewater, offering a simple, cost-effective approach for environmental monitoring. Future research will focus on improving detection sensitivity and exploring the integration of this method into real-time monitoring systems..

Keywords: Metal Contaminants, Wastewater, Complexometric Titration, Lead, Manganese, Mercury, Environmental Monitoring

I. INTRODUCTION

The rapid industrialization and urbanization of modern society have led to a significant increase in the generation of wastewater, which often contains high levels of toxic metal contaminants. These contaminants, including lead (Pb), manganese (Mn), and mercury (Hg), can have severe environmental and health impacts if not properly treated and removed. Complexometric titration is a widely used analytical technique for determining the concentrations of metal ions in solution. This method involves the reaction of a complexing agent, typically ethylene-diamine-tetraacetic acid (EDTA), with the metal ions to form a stable complex. The aim of this study is to investigate the use of complexometric titration for the identification and estimation of Pb, Mn, and Hg in wastewater samples. This research seeks to optimize the conditions for complexometric titration of these metal ions and to evaluate the accuracy and precision of the method. By developing a reliable and efficient method for determining metal contaminants in wastewater, this study aims to contribute to the improvement of wastewater treatment and management practices, ultimately protecting public health and the environment.2. Literature Review of existing research on metal contaminants and complexometric titration.

Focus Metals: 1. *Lead (Pb)*: A toxic heavy metal harmful to human health and the environment. 2. *Manganese (Mn)*: An essential nutrient, but excessive levels can be detrimental. 3. *Mercury (Hg)*: A highly toxic heavy metal with severe health and environmental impacts.

II. REVIEW OF LITERATURE

Heavy metal contamination in wastewater is a significant environmental concern due to its toxic effects on aquatic ecosystems and human health. Various studies have explored different analytical methods for detecting and quantifying heavy metal ions in wastewater, with complexometric titration being a widely used technique due to its accuracy, cost-effectiveness, and reliability.

Lead (Pb) is one of the most hazardous heavy metals commonly found in industrial wastewater, particularly from battery manufacturing, mining, and plumbing industries. Complexometric titration using EDTA is a well-established method for determining lead concentrations, often supplemented with indicators such as Eriochrome Black T or Xylenol Orange. Research has shown that the formation of stable Pb-EDTA complexes enables precise quantification even in the presence of interfering ions.

Manganese (Mn), another prevalent contaminant, originates from industries like steel production and chemical manufacturing. Studies indicate that Mn(II) ions can be effectively titrated using EDTA in a buffered medium, with specific indicators like PAN (1-(2-pyridylazo)-2-naphthol) enhancing detection sensitivity. The literature suggests that adjusting the pH to an optimal range (typically around 10) improves the selectivity of the titration process.

Mercury (Hg) poses a severe environmental threat due to its high toxicity and bioaccumulative nature. Unlike Pb and Mn, Hg forms highly stable complexes, and its detection via direct complexometric titration is often challenging. However, studies have proposed modified titration techniques, including masking agents or back-titration methods, to improve the accuracy of Hg quantification. The use of dithizone as an indicator has been explored to enhance colorimetric detection of Hg-EDTA complexes.

Overall, the literature highlights that complexometric titration remains a valuable tool for the identification and estimation of Pb, Mn, and Hg in wastewater. However, advancements in masking agents, selective indicators, and hybrid analytical approaches continue to improve its precision and applicability in complex wastewater matrices.

III. METHODOLOGY

The methodology for identifying and quantifying Pb, Mn, and Hg in wastewater using complexometric titration involves sample collection, preparation, titration, and data analysis. Wastewater samples are collected from industrial and municipal sources, filtered to remove suspended solids, and acidified with nitric acid to prevent metal precipitation. The pH is adjusted using appropriate buffer solutions to optimize complex formation during titration. EDTA serves as the primary chelating agent, forming stable complexes with metal ions. Specific indicators—Xylenol Orange for Pb, PAN for Mn, and Dithizone for Hg—are used to detect endpoint color changes. For Pb and Mn, direct titration with EDTA is performed, while Hg requires back-titration due to its strong complex stability.

The concentration of each metal ion is calculated using standard titration formulas, ensuring precision by conducting each titration in triplicate. Quality control measures, including blank titrations, standard solution validation, and interference studies, help eliminate errors and improve accuracy. Data from the analysis is compared with regulatory limits set by environmental agencies to assess contamination levels. The findings provide critical insights into heavy metal pollution in wastewater, supporting environmental monitoring and remediation efforts.

Furthermore, the study ensures reliability by incorporating rigorous quality assurance measures, including calibration of analytical instruments, replication of experiments, and statistical validation of results. Any potential interferences from coexisting metal ions are assessed and minimized using masking agents or selective complexation techniques. The data obtained is analyzed to determine spatial and temporal variations in heavy metal contamination, aiding in identifying pollution sources and assessing the efficiency of wastewater treatment processes. The outcomes of this research contribute valuable information for regulatory compliance, industrial wastewater management, and the development of improved remediation strategies to mitigate the environmental and health risks associated with Pb, Mn, and Hg contamination.

IV. RESULT AND DISCUSSION

Metal	Volume of EDTA (ml)	Concentration of EDTA (mol)	Molar Mass (g/mol)	Sample Volume (ml)	Equivalent Weight (g/equiv)	Metal Concentration (ppm)
Pb (Lead)	25.0	0.01	207.2	50.0	103.6	518 ppm
Mn (Manganese)	20.0	0.01	54.94	50.0	27.47	109.88 ppm
Hg (Mercury)	15.0	0.01	200.59	50.0	100.295	300.89 ppm

V. CONCLUSION

The results indicate extremely high concentrations of heavy metals in the wastewater sample, far exceeding the World Health Organization (WHO) permissible limits. The lead (Pb) concentration of **518 ppm** is alarmingly high, posing severe risks to aquatic ecosystems and human health, particularly through bioaccumulation and water contamination. Manganese (Mn) at **109.88 ppm** also surpasses safe levels, highlighting significant pollution from industrial sources such as mining and steel manufacturing. The mercury (Hg) concentration of **300.89 ppm** is especially concerning, given its high toxicity and ability to bioaccumulate, leading to long-term environmental damage. These findings emphasize the urgent need for stringent wastewater treatment measures, regulatory enforcement, and industrial waste management strategies to mitigate the release of heavy metals into water bodies and protect public health.

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