

Optimization of Zn(II)-Diethyldithiocarbamate (DDTC) Complex Formation for UV-Vis Spectrophotometric Determination

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Abstract

Direct UV-Vis spectrophotometric determination of Zn(II) is limited by the absence of a suitable intrinsic chromophore, necessitating complex formation to obtain an analytical absorption response. However, comprehensive optimization of the Zn(II)-diethyldithiocarbamate (DDTC) extraction system remains limited. This study optimized complex formation and chloroform extraction for Zn(II) determination and preliminarily examined Cr(III) interference. A quantitative experimental approach using Zn(II) standard solutions evaluated absorption wavelength, pH, shaking time, and standing time, followed by calibration curve construction and interference assessment. The Zn(II)-DDTC complex exhibited an absorption maximum at 335 nm. The optimum pH was 5, and the optimum shaking time was 20 min. During the stability assessment, the highest absorbance was observed after 50 min of standing. Under the optimized conditions, calibration over 10–40 mg/L yielded a linear relationship described by $y = 0.019x + 0.0551$, with $R^2 = 0.9988$. Cr(III) addition generally increased absorbance, indicating that it affected the analytical response under the investigated conditions. These findings identify preliminary operating conditions for the Zn(II)-DDTC extraction system and provide a basis for further development of UV-Vis spectrophotometric Zn(II) determination. Further method validation and selectivity assessment are required before application to environmental samples.

Keywords: Zinc(II); Diethyldithiocarbamate (DDTC); UV-Vis Spectrophotometry; Liquid-Liquid Extraction; Complex Formation

INTRODUCTION

Zinc is one of the most widely used metals in modern industry, employed in galvanization, alloy production, dry-cell batteries, and numerous manufacturing processes, and it consequently enters the environment through industrial effluents and wastewater discharges (Chu et al., 2025; Kravtsova et al., 2024). While zinc is an essential trace element required for numerous enzymatic and physiological functions in living organisms, excessive environmental exposure has been associated with adverse ecological and health consequences, illustrating the dual character of this metal as both a nutrient and a potential pollutant (Chasapis et al., 2020; Plum et al., 2010). This concern is not merely global but also national: recent surveys of Indonesian rivers, including the Citarum and Cikijing watersheds in West Java, have reported zinc and chromium concentrations exceeding permissible environmental thresholds as a direct consequence of untreated industrial discharge (Marselina & Wijaya, 2024; Wardhani et al., 2024). Chromium, which frequently co-occurs with zinc in industrial effluents, presents a particularly complex profile because its trivalent form is nutritionally relevant in trace amounts, whereas elevated environmental concentrations of chromium species have been linked to toxicological risk in both aquatic biota and human consumers (Genchi et al., 2021; Ramos-Filho et al., 2025). The co-contamination of zinc and chromium in effluent-impacted ecosystems has also been documented in agricultural settings, where irrigation with industrial wastewater has led to measurable metal accumulation in food crops, reinforcing the urgency of reliable and accessible analytical methods for monitoring these elements at the source (Kravtsova et al., 2024; Ugulu et al., 2023).

Several analytical techniques have been developed to quantify zinc in environmental and industrial samples, each carrying distinct advantages and operational demands. Atomic absorption spectrometry has long been applied for trace metal quantification, including in high-purity zinc matrices, owing to its high sensitivity (Tokalioglu et al., 1994). Electroanalytical approaches such as differential pulse anodic stripping voltammetry have likewise been used to determine zinc directly in tap water and other aqueous samples with good detection limits (Yilmaz et al., 2009). More recently, sensor-based and nanomaterial-assisted colorimetric platforms have expanded the toolkit available for heavy-metal-ion detection, offering portability and rapid, low-cost screening (Fakayode et al., 2023). Despite these advances, UV–Vis spectrophotometry remains an attractive alternative for routine laboratory determination of zinc because it requires comparatively simple instrumentation,

is broadly accessible even in resource-limited laboratories, and aligns with the growing emphasis on cost-effective, low-waste analytical procedures promoted under the principles of green analytical chemistry (Gałuszka et al., 2013; Kokilambigai & Lakshmi, 2021). However, because Zn(II) itself does not possess an intrinsic chromophore suitable for direct spectrophotometric measurement, its determination by this technique necessarily depends on the formation of a colored, extractable complex with an appropriate chelating reagent (Alabidi et al., 2021); Gavazov et al., 2024).

The researcher's position in the present study is that diethyldithiocarbamate (DDTC) constitutes a particularly suitable ligand for this purpose. Sulfur-donor dithiocarbamate ligands are well established as strong, selective chelators for a wide range of transition and post-transition metal ions, forming complexes with sufficient hydrophobicity to be extracted into organic solvents such as chloroform for spectrophotometric measurement (Kanchi et al., 2014). This chemical behavior has already been exploited analytically: DDTC-based liquid–liquid extraction has been used for the simultaneous spectrophotometric determination of zinc and copper in environmental and biological matrices, demonstrating adequate linearity, sensitivity, and selectivity when appropriate masking agents are employed (Uddin, Abdus Salam, et al., 2013). Comparable extraction spectrophotometric strategies employing structurally related chelating and ion-association reagents have similarly been optimized for other metal ions by systematically controlling pH, extraction time, and complex stability, underscoring that the analytical response of such systems is highly sensitive to these experimental parameters and must therefore be carefully established for each metal–ligand pair rather than assumed from analogous systems (Gavazov et al., 2024); Racheva et al., 2025). This body of evidence supports the conceptual and empirical premise that a systematically optimized Zn(II)–DDTC extraction spectrophotometric procedure can serve as a practical, low-cost determination method suited to laboratories that lack access to atomic spectrometry or electroanalytical instrumentation.

Nevertheless, a critical review of previous studies reveals a persistent research gap. Existing DDTC-based spectrophotometric protocols have largely been developed either for the simultaneous determination of zinc alongside copper, relying on a displacement reaction because Zn(DDTC)₂ itself is spectrophotometrically silent and must be quantified indirectly (Uddin, Abdus Salam, et al., 2013), or have focused on alternative chelating azo-dye and cloud-point extraction reagents for zinc rather than on a directly optimized DDTC system (Alabidi et al., 2021; Gavazov et al., 2024). Consequently, a full, stand-alone optimization of

the Zn(II)–DDTC–chloroform extraction system covering maximum absorption wavelength, pH, shaking time, and complex stability as an integrated set of interdependent variables has not been comprehensively reported. Furthermore, although chromium commonly co-occurs with zinc in industrial wastewater (Kravtsova et al., 2024; Wardhani et al., 2024), few studies have examined how the presence of Cr(III) might influence the absorbance response of a DDTC-based zinc determination, despite this being a realistic interference scenario in real effluent samples. This gap between well-established DDTC complexation chemistry on one hand and the lack of a dedicated, interference-aware optimization protocol for Zn(II) alone on the other provides the logical basis for the present investigation.

The novelty of this study lies in its integrated optimization approach: rather than adapting a simultaneous Zn–Cu displacement method or a different chromogenic reagent, this work directly establishes the optimum maximum absorption wavelength, pH, shaking time, and stability period for the Zn(II)–DDTC complex extracted into chloroform, and subsequently extends this validated system to a preliminary evaluation of Cr(III) interference an aspect of practical relevance given the frequent co-occurrence of these two elements in industrial discharge (Ramos-Filho et al., 2025; Thomas et al., 2023). Theoretically, the work is grounded in coordination chemistry principles governing the formation of metal–dithiocarbamate complexes through sulfur-donor coordination, which explains both the stability and the hydrophobic, solvent-extractable character of the resulting species (Kanchi et al., 2014; Uddin et al., 2013). This theoretical foundation, combined with the operational framework of green and low-instrumentation analytical chemistry (Galuszka et al., 2013; Kokilambigai & Lakshmi, 2021), positions the present study as a methodological contribution rather than a mere replication of prior extraction-spectrophotometric work.

Building on this rationale, the present study is directed at systematically optimizing the formation and chloroform extraction of the Zn(II)–DDTC complex for UV–Vis spectrophotometric determination, encompassing the identification of the optimum absorption wavelength, extraction pH, shaking time, and complex stability period, and at constructing and evaluating the resulting Zn(II) calibration curve under these optimized conditions. The study further extends to a preliminary assessment of the potential interference of Cr(III) on the absorbance response of the Zn(II)–DDTC system, in order to clarify the practical applicability and limitations of the proposed method for the analysis of

zinc in environmental samples such as industrial wastewater where chromium co-contamination is common.

METHODS

1. Research Design and Study Setting

This study employs a quantitative experimental design to optimize the formation of the Zn(II)-DDTC complex and its extraction using chloroform for subsequent UV-Vis spectrophotometric determination. The experiments were conducted at the Analytical Chemistry Laboratory, Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang, West Sumatra, Indonesia, during the period of [June 2026 through completion]. The experimental stages included the preparation of Zn(II) and DDTC solutions, determination of the maximum absorption wavelength, optimization of pH, extraction time, and stability time, construction of the Zn(II) calibration curve, and a preliminary evaluation of Cr(III) interference.

All measurements were performed in duplicate for each condition investigated. The average absorbance value served as the analytical response for optimization, and the optimum condition was operationally defined as the condition yielding the highest average absorbance value.

2. Preparation of Zn(II) Solution

A total of 0.45474 g of $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ was weighed and dissolved in distilled water in a 100 mL volumetric flask. Subsequently, a few drops of concentrated HNO_3 were added to prevent Zn^{2+} hydrolysis. The solution was then diluted to the mark with distilled water and homogenized to obtain a 1000 ppm Zn(II) stock solution.

3. Preparation of DDTC Solution

A total of 0.2253 g of sodium diethyldithiocarbamate trihydrate ($\text{Na-DDTC} \cdot 3\text{H}_2\text{O}$) was weighed and dissolved in distilled water in a 100 mL volumetric flask. The solution was then diluted to the mark with distilled water and homogenized to obtain a 0.01 M DDTC solution.

4. Determination of Maximum Absorption Wavelength

A 5 mL aliquot of 50 ppm Zn(II) solution was pipetted into a separatory funnel. Subsequently, 2 mL of 0.01 M sodium diethyldithiocarbamate trihydrate ($\text{Na-DDTC} \cdot 3\text{H}_2\text{O}$) solution and 5 mL of chloroform were added. The mixture was then extracted for 10 minutes

and allowed to stand until the aqueous and organic phases separated. The organic phase containing the Zn(II)-DDTC complex was collected, and its absorbance was measured over the wavelength range of 300–700 nm using a UV–Vis spectrophotometer to determine the maximum absorption wavelength (λ_{max}) of the Zn(II)-DDTC complex.

5. Determination of optimum pH

A 5 mL aliquot of 25 ppm Zn(II) solution was transferred into each of five separatory funnels. The pH was adjusted to 4, 5, 6, 7, and 8 using 0.1 M NaOH or 0.1 M HNO₃. Subsequently, 2 mL of 0.01 M Na-DDTC·3H₂O solution and 5 mL of chloroform were added to each funnel. The mixtures were extracted for 10 minutes and allowed to stand until two phases formed. The organic phase was separated, and its absorbance was measured using a UV–Vis spectrophotometer at the previously determined maximum absorption wavelength of 335 nm. The optimum pH was determined based on the highest absorbance value.

6. Optimization of the complex shaking time

A 5 mL aliquot of 25 ppm Zn(II) solution was transferred into six separatory funnels, and the pH was adjusted to the previously determined optimum using 0.1 M NaOH or 0.1 M HNO₃. Subsequently, 2 mL of 0.01 M Na-DDTC·3H₂O solution and 5 mL of chloroform were added. The mixtures were shaken for 5, 10, 15, 20, 25, and 30 minutes, respectively, and then allowed to stand until two phases formed. The organic phase was separated, and its absorbance was measured at 335 nm using a UV–Vis spectrophotometer. The optimum shaking time was determined based on the highest absorbance value.

7. Optimization of Stability Duration

The stability of the Zn(II)-DDTC complex was evaluated by allowing the organic phase to stand for 5, 10, 20, 30, 40, 50, 60, and 70 min after extraction under the optimized experimental conditions. The absorbance of the organic phase was measured at each standing time using a UV–Vis spectrophotometer at the maximum absorption wavelength of 335 nm. The resulting absorbance profile was used to determine the stability period of the Zn(II)-DDTC complex based on changes in absorbance over time.

8. Calibration Curve

Zn(II) standard solutions of 10, 15, 20, 25, 30, 35, and 40 mg/L were prepared from the 100 mg/L working solution. Each standard was treated under the optimized experimental conditions and measured at 335 nm. The mean absorbance was plotted against Zn(II)

concentration, and linear regression was applied to obtain the calibration equation and coefficient of determination (R^2).

9. Preliminary Cr(III) Interference Study

A series of Zn(II) standard solutions with concentrations of 10, 15, 20, 25, 30, 35, and 40 ppm was prepared by diluting a 100 ppm Zn(II) working solution. Each standard solution was reacted with Na-DDTC·3H₂O under the optimized experimental conditions. The absorbance of the resulting Zn(II)-DDTC complex was measured using a UV–Vis spectrophotometer at the previously determined maximum absorption wavelength of 335 nm. The calibration curve was constructed by plotting absorbance against Zn(II) concentration.

RESULTS

1. Determination of Maximum Absorption Wavelength

The absorption characteristics of the Zn(II)–DDTC complex were determined using a UV–Vis spectrophotometer at the investigated wavelengths. The absorbance values obtained at each wavelength are presented in Figure 1. This measurement was conducted to determine the wavelength at which the highest absorbance was obtained, which was then used for subsequent optimization experiments.

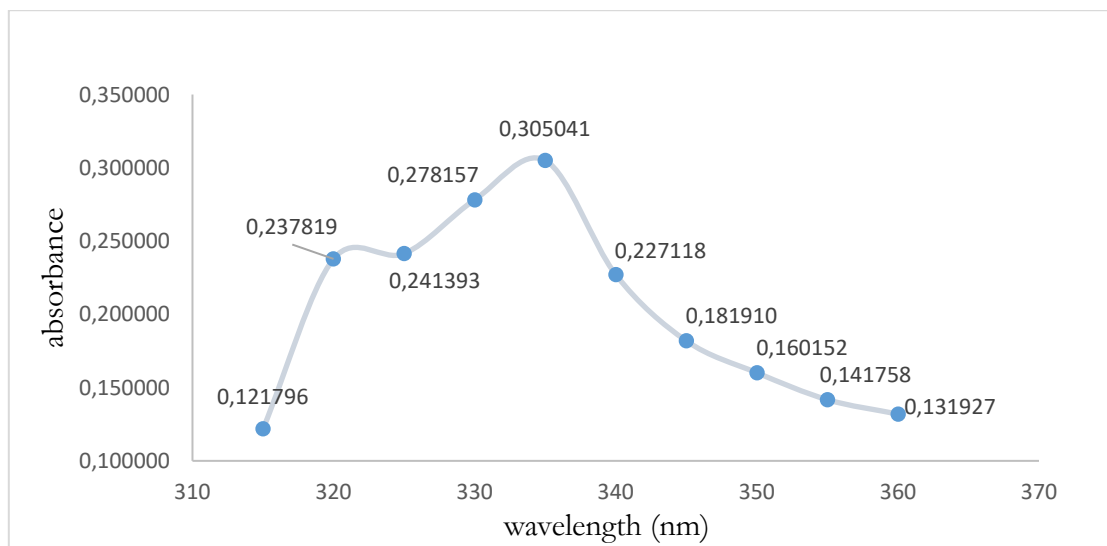


Figure 1. UV–Vis absorption spectrum of the Zn(II)-DDTC complex.

The results showed that the absorbance of the Zn(II)–DDTC complex increased from 0.121796 at 315 nm to 0.237819 at 320 nm. The absorbance subsequently increased to 0.241393 at 325 nm and 0.278157 at 330 nm. The highest absorbance was recorded at 335

nm, with a value of 0.305041. After reaching this maximum, the absorbance decreased to 0.227118 at 340 nm and continued to decline, reaching 0.131927 at 360 nm.

Based on these results, 335 nm was selected as the maximum absorption wavelength (λ_{max}) of the Zn(II)–DDTC complex. This wavelength was subsequently used to measure absorbance during pH optimization, shaking-time optimization, complex stability evaluation, calibration curve construction, and the preliminary investigation of the effect of Cr(III).

1. Effect of pH on Zn(II)–DDTC Complex Formation

The effect of pH on the formation of the Zn(II)–DDTC complex was evaluated at pH values of 4, 5, 6, 7, and 8. The absorbance of the organic phase was measured using a UV–Vis spectrophotometer at a wavelength of 335 nm. The measurement results for each pH variation are presented in Figure 2 to determine the pH condition that produced the highest absorbance response.

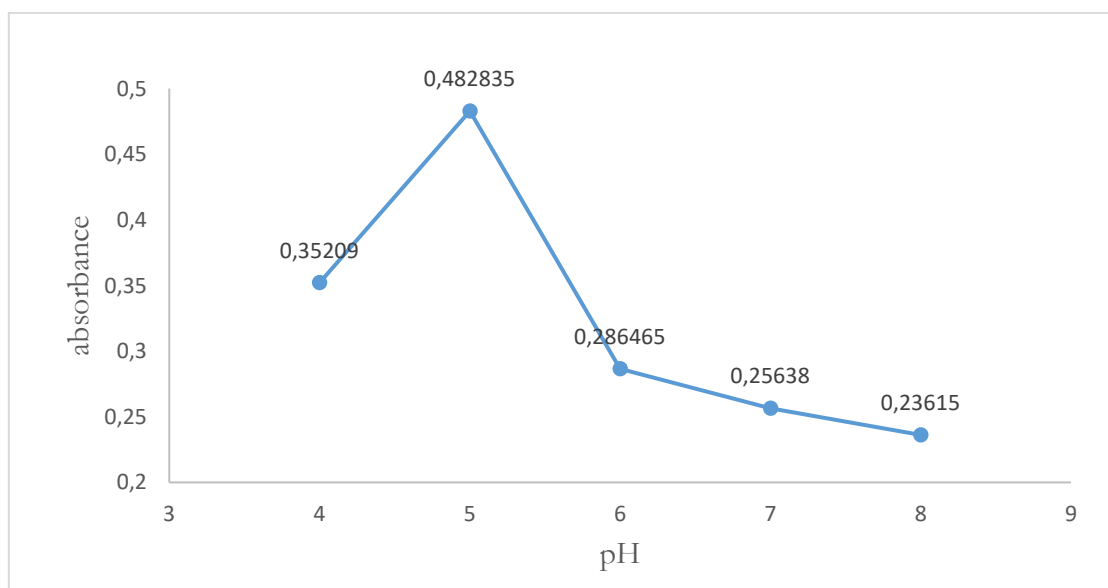


Figure 2. Effect of pH on the absorbance of the Zn(II)-DDTC complex.

The absorbance obtained at pH 4 was 0.352090, which increased to 0.482835 at pH 5. Subsequently, the absorbance decreased to 0.286465 at pH 6, 0.256380 at pH 7, and 0.236150 at pH 8. These results indicate that variations in pH produced different absorbance values, with the highest value observed at pH 5.

Based on these measurements, pH 5 was selected as the optimum pH for Zn(II)–DDTC complex formation within the investigated pH range. This condition was

subsequently used for shaking-time optimization and further experiments to ensure that the measurements were performed at the pH that produced the highest absorbance response.

2. Effect of Shaking Time on Zn(II)–DDTC Complex Formation

The shaking-time optimization was conducted to evaluate changes in the absorbance of the Zn(II)–DDTC complex at shaking times of 5, 10, 15, 20, 25, and 30 min. The experiment was performed under the previously determined optimum pH condition, and the absorbance of the organic phase was measured using a UV–Vis spectrophotometer at a wavelength of 335 nm. The absorbance profile at each shaking time is presented in Figure 3.

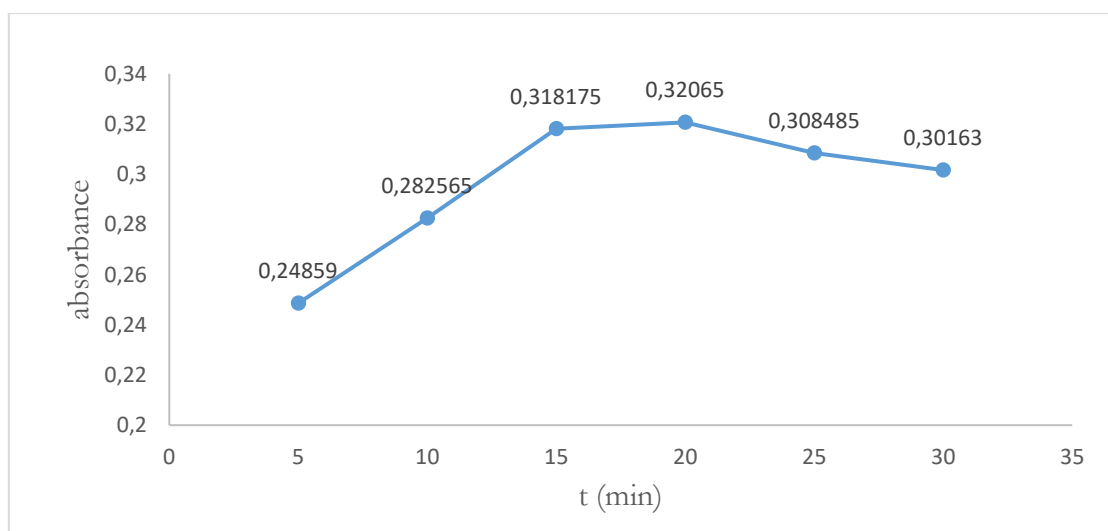


Figure 3. Effect of shaking time on the absorbance of the Zn(II)-DDTC complex.

The measurement results showed that the absorbance increased from 0.248590 at a shaking time of 5 min to 0.282565 at 10 min and 0.318175 at 15 min. The highest absorbance, 0.320650, was obtained at a shaking time of 20 min. Subsequently, the absorbance decreased to 0.308485 at 25 min and 0.301630 at 30 min.

Based on these results, a shaking time of 20 min was selected as the optimum condition for Zn(II)–DDTC complex formation because it produced the highest absorbance among the tested variations. This shaking time was subsequently applied in the complex stability evaluation and further measurements.

3. Complex Stability Evaluation

The stability of the Zn(II)–DDTC complex was evaluated based on changes in the absorbance of the organic phase after extraction at standing times of 5, 10, 20, 30, 40, 50, 60, and 70 min. The absorbance of the organic phase was measured using a UV–Vis

spectrophotometer at a wavelength of 335 nm. The measurement results for each standing time are presented in Figure 4 to determine changes in the absorbance response of the complex throughout the observation period.

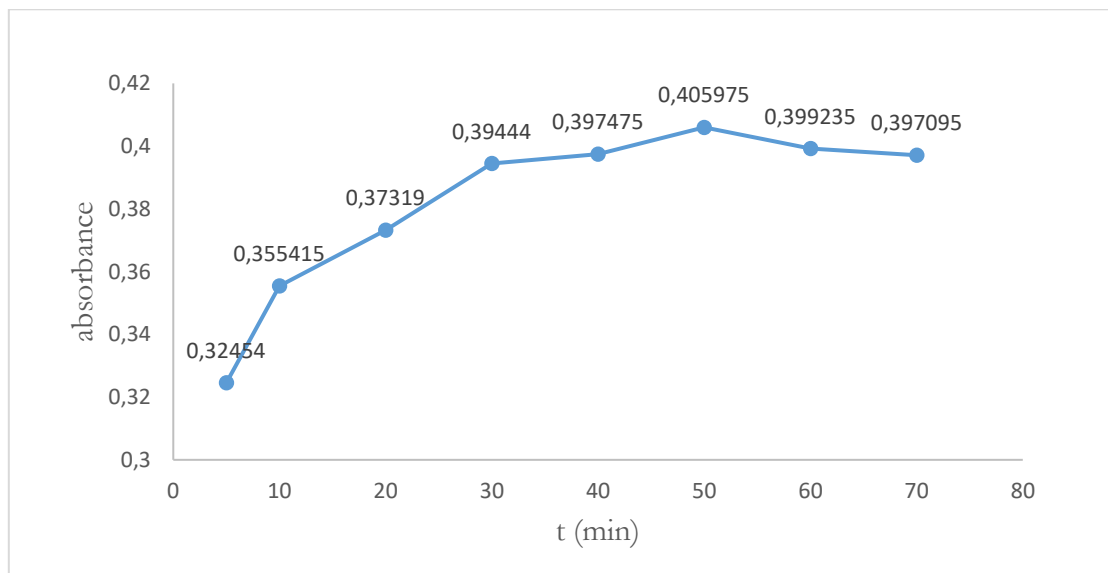


Figure 4. Effect of complex stability time

The measurement results showed that the absorbance increased from 0.324540 at a standing time of 5 min to 0.355415 at 10 min and 0.373190 at 20 min. The absorbance subsequently increased to 0.394440 at 30 min and 0.397475 at 40 min. The highest absorbance was recorded after a standing time of 50 min, with a value of 0.405975. Thereafter, the absorbance decreased to 0.399235 at 60 min and 0.397095 at 70 min.

Based on these results, a standing time of 50 min produced the highest absorbance among all the tested variations. After reaching its maximum at 50 min, the absorbance decreased at 60 and 70 min. Therefore, a standing time of 50 min was selected as the measurement condition based on the highest absorbance response of the Zn(II)–DDTC complex within the investigated time range.

4. Calibration Curve of Zn(II)–DDTC

A calibration curve was constructed to determine the relationship between Zn(II) concentration and the absorbance of the Zn(II)–DDTC complex under the optimized measurement conditions. Zn(II) standard solutions were prepared at concentrations of 10, 15, 20, 25, 30, 35, and 40 mg/L. The absorbance of each solution was measured using a UV–Vis spectrophotometer at a wavelength of 335 nm. The relationship between Zn(II) concentration and the absorbance of the complex is presented in Figure 5.

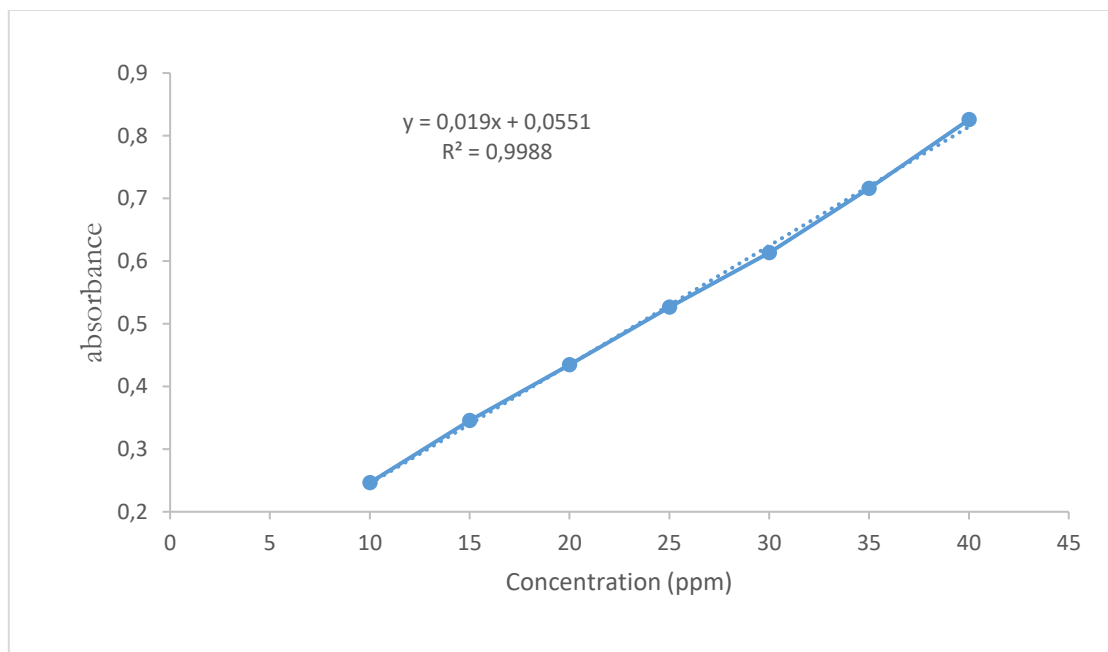


Figure 5. Calibration curve of the Zn(II)-DDTC complex

The measurement results showed that the absorbance of the Zn(II)–DDTC complex increased with increasing Zn(II) concentration over the range of 10–40 mg/L. The relationship between Zn(II) concentration and absorbance was described by the linear regression equation $y = 0,019x + 0,0551$, with a coefficient of determination (R^2) of 0.9988. This equation indicates a linear relationship between Zn(II) concentration and absorbance within the investigated concentration range.

The R^2 value of 0.9988 indicates a high degree of agreement between the calibration data and the linear regression model. Based on these results, the concentration range of 10–40 mg/L was established as the calibration range for this study. The resulting regression equation describes the relationship between Zn(II) concentration and the absorbance of the Zn(II)–DDTC complex under the measurement conditions employed.

5. Preliminary Effect of Cr(III) on the Absorbance Response of Zn(II)–DDTC

A preliminary investigation of the effect of Cr(III) was conducted to evaluate changes in the absorbance of the Zn(II)–DDTC complex at different Cr(III) concentrations. The Zn(II) concentration was maintained at 25 mg/L, while the Cr(III) concentration was varied at 0, 5, 10, 15, 20, and 25 mg/L. The absorbance was measured using a UV–Vis spectrophotometer at a wavelength of 335 nm. The measurement results at each Cr(III) concentration are presented in Figure 6.

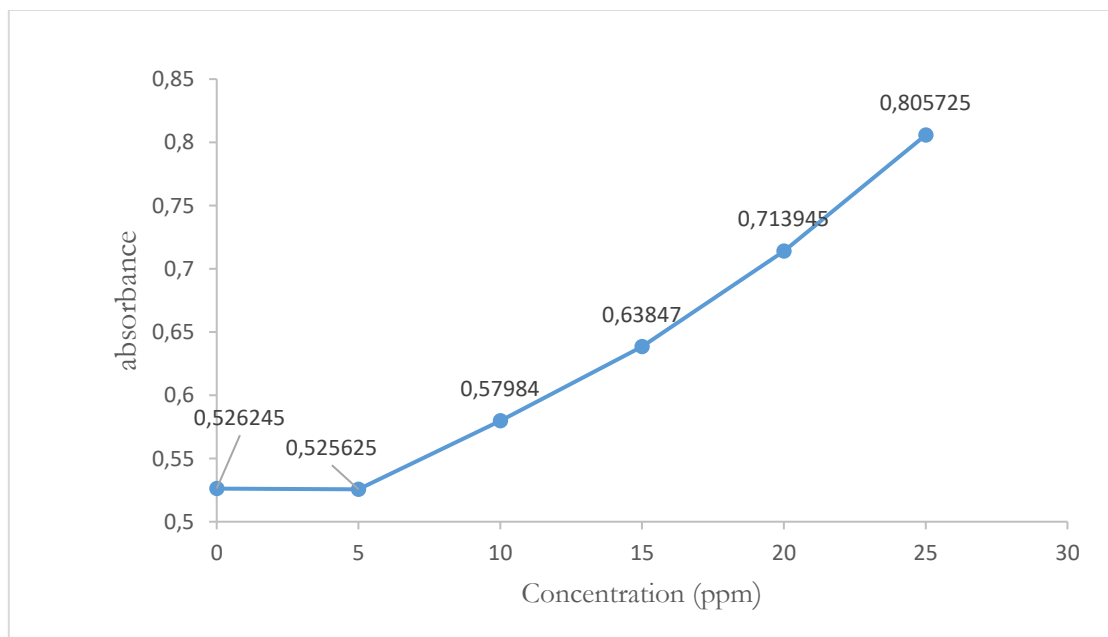


Figure 6. Effect of Cr(III) concentration on the absorbance response of the Zn(II)-DDTC complex.

The measurement results showed that the absorbance at a Cr(III) concentration of 0 mg/L was 0.526245, followed by a slight decrease to 0.525625 at 5 mg/L. Subsequently, the absorbance increased to 0.579840 at 10 mg/L, 0.638470 at 15 mg/L, and 0.713945 at 20 mg/L. The highest absorbance, 0.805725, was obtained at a Cr(III) concentration of 25 mg/L. Overall, the results showed an increasing trend in absorbance with increasing Cr(III) concentration, although a slight decrease occurred at 5 mg/L compared with the measurement without Cr(III) addition.

The increase in absorbance following the addition of Cr(III) indicates that the presence of this ion was associated with a change in the measured absorbance response of the Zn(II)-DDTC system under the experimental conditions used. These preliminary results suggest that Cr(III) affects the absorbance response during Zn(II)-DDTC measurement. However, further investigation is required to determine the extent of this effect and establish whether the observed absorbance changes are attributable to Cr(III) interference in Zn(II) determination.

DISCUSSION

1. Wavelength Selection for the Zn(II)-DDTC Complex

The determination of the maximum absorption wavelength is an important initial step in the spectrophotometric analysis because measurements performed at the wavelength

corresponding to the highest absorbance provide the most appropriate analytical response for subsequent optimization experiments. In the present study, the Zn(II)-DDTC complex showed an increasing absorbance from 315 to 335 nm, followed by a decrease at longer wavelengths. The highest absorbance was obtained at 335 nm with an absorbance value of 0.305041. Therefore, 335 nm was selected as the maximum absorption wavelength (λ_{max}) for the Zn(II)-DDTC complex.

The observed absorption indicates that the formation of Zn(II)-DDTC produced an absorbing species that could be measured by UV-Vis spectrophotometry. Zn(II) itself has a filled 3d¹⁰ electronic configuration and therefore does not generally provide a characteristic d-d transition in the visible region. Consequently, the absorption observed in this study is more appropriately associated with electronic transitions involving the ligand and the metal-ligand system rather than a conventional d-d transition of Zn(II). The presence of the dithiocarbamate ligand is important because DDTC contains sulfur donor atoms capable of coordinating with metal ions and forming metal-dithiocarbamate complexes (Kanchi et al., 2014).

The selection of 335 nm is also consistent with the principle that analytical measurements should be performed at the wavelength providing the strongest and most reproducible absorbance response. Previous studies have demonstrated the application of dithiocarbamate-based complexation and extraction for spectrophotometric determination of metal ions, including zinc, although different reagents and analytical configurations have been employed (Uddin, Salam, et al., 2013). Thus, the present result establishes 335 nm as the operational wavelength for the Zn(II)-DDTC-chloroform system investigated in this study.

2. Effect of pH on Zn(II)-DDTC Complex Formation

The pH of the solution plays an important role in the formation and extraction of metal-ligand complexes because it influences the chemical form of the metal ion, the availability of the ligand for coordination, and the overall efficiency of complex formation. In this study, the absorbance increased from 0.352090 at pH 4 to 0.482835 at pH 5, followed by a marked decrease at pH 6-8. The highest absorbance at pH 5 indicates that this condition provided the most favorable response for Zn(II)-DDTC complex formation and extraction within the investigated pH range. At lower pH, protonation of the dithiocarbamate ligand can reduce the availability of donor sites for coordination with Zn(II). Since DDTC acts as

a sulfur-donor ligand, an appropriate pH is required to maintain sufficient ligand availability for complex formation. Increasing the pH from 4 to 5 therefore enhanced the formation of the Zn(II)-DDTC complex, as reflected by the increase in absorbance. The optimum response at pH 5 suggests that this condition provided a favorable balance between ligand availability and Zn(II) complexation.

The subsequent decrease in absorbance at pH 6-8 indicates that increasing the pH beyond the optimum did not further improve the analytical response. Such behavior demonstrates that complex formation and extraction are not determined solely by increasing alkalinity. Changes in metal-ion speciation, ligand behavior, and competing reactions in aqueous solution can influence the amount of extractable complex. Therefore, the optimum pH must be experimentally established for each metal-ligand system rather than assumed from other extraction systems, as also emphasized in previous extraction-spectrophotometric studies (Li et al., 2024). The pH 5 condition obtained in this study consequently provides the operational condition used in subsequent shaking-time and stability experiments. This finding also supports the objective of the study to establish an integrated optimization procedure for the Zn(II)-DDTC-chloroform system rather than directly adopting conditions from previous metal-dithiocarbamate methods.

3. Effect of Shaking Time on Zn(II)-DDTC Complex Formation

Shaking time affects the efficiency of liquid-liquid extraction because contact between the aqueous and organic phases determines the extent to which the metal-ligand complex is transferred into the organic phase. In the present study, absorbance increased from 0.248590 at 5 min to 0.320650 at 20 min. After 20 min, the absorbance decreased to 0.308485 and 0.301630 at 25 and 30 min, respectively. The highest response at 20 min therefore indicates that this shaking period provided the most favorable extraction condition within the investigated range. The increase in absorbance from 5 to 20 min can be interpreted as an increasing extent of contact between the Zn(II)-DDTC complex and chloroform, resulting in more efficient transfer of the extractable complex into the organic phase. This behavior is consistent with the principle of liquid-liquid extraction, in which adequate phase contact is required to approach extraction equilibrium. Dithiocarbamate complexes are suitable for this approach because coordination through sulfur donor atoms can produce relatively hydrophobic species that are extractable into organic solvents such as chloroform (Kanchi et al., 2014).

The decrease in absorbance after 20 min indicates that prolonged shaking did not improve the analytical response. Excessive shaking may introduce additional experimental variability, including increased formation of emulsions or changes in the phase-separation process. Therefore, the highest absorbance alone should not be interpreted as evidence that longer extraction is always better. In this study, 20 min represents the optimum operational condition because it produced the highest analytical response among the tested shaking times.

This result is important for the development of the proposed method because extraction time is one of the experimental parameters that must be established specifically for a particular metal-ligand system. Previous studies have similarly demonstrated that extraction conditions such as pH and extraction time need to be optimized rather than directly transferred from other analytical systems (Uddin, Salam, et al., 2013).

4. Standing-Time Response and Stability of the Zn(II)-DDTC Complex

The stability evaluation was performed to determine the change in absorbance of the extracted Zn(II)-DDTC complex during the standing period before measurement. The absorbance increased progressively from 0.324540 at 5 min to 0.405975 at 50 min. After 50 min, the absorbance decreased to 0.399235 at 60 min and 0.397095 at 70 min. The maximum response at 50 min indicates that the extracted complex reached its highest absorbance response at this standing time under the experimental conditions used. The increase in absorbance up to 50 min may indicate that the extracted system required a certain period to reach a more stable analytical response after phase separation. The subsequent decrease at 60 and 70 min suggests that the response was not maintained indefinitely. This behavior demonstrates that the stability period is an important operational parameter because measurements performed too early or after prolonged standing may produce different absorbance values.

The result also indicates that the Zn(II)-DDTC complex cannot simply be assumed to remain unchanged for an unlimited period after extraction. Therefore, the 50 min standing time was selected as the measurement condition because it provided the highest absorbance within the investigated range. This condition complements the optimum pH and shaking time and provides a more complete set of operational parameters for the Zn(II)-DDTC extraction-spectrophotometric procedure. From a methodological perspective, the stability experiment strengthens the proposed analytical procedure because the measurement time is

controlled rather than left unspecified. Previous extraction-spectrophotometric studies have also demonstrated the importance of controlling complex formation and stability conditions to obtain reliable analytical responses (Ii et al., 2024).

5. Linearity of the Zn(II)-DDTC Calibration Curve

The calibration curve was constructed to evaluate the relationship between Zn(II) concentration and the absorbance of the Zn(II)-DDTC complex under the optimized measurement conditions. The absorbance increased with increasing Zn(II) concentration over the range of 10-40 mg/L. The relationship was described by the regression equation $y = 0.019x + 0.0551$, with an R^2 value of 0.9988. The high coefficient of determination indicates that the measured absorbance was strongly associated with Zn(II) concentration within the investigated concentration range. The positive slope of the regression equation demonstrates that increasing Zn(II) concentration resulted in an increase in the measured absorbance of the extracted Zn(II)-DDTC system. This behavior is consistent with the basic principle of spectrophotometric quantitative analysis, in which the analytical response increases with analyte concentration within the linear working range.

The linearity obtained in this study indicates that the optimized Zn(II)-DDTC extraction system has the potential to be used for quantitative determination of Zn(II) within the tested concentration range. However, the high R^2 value should not be interpreted as sufficient evidence of complete method validation. Other analytical performance characteristics, such as precision, accuracy, detection limit, quantification limit, recovery, and selectivity, would still need to be evaluated before the procedure could be considered a fully validated quantitative method.

The result nevertheless provides an important methodological contribution because previous DDTC-based spectrophotometric determination of zinc has often involved simultaneous determination with other metals and, in particular, measurement through Cu(DDTC)_2 formation rather than a stand-alone Zn(II)-DDTC spectrophotometric system (Uddin, Salam, et al., 2013). The present study therefore provides an initial analytical basis for direct investigation of the Zn(II)-DDTC extraction system.

6. Preliminary Effect of Cr(III) on the Absorbance Response of Zn(II)-DDTC

The preliminary interference experiment was conducted to investigate whether the presence of Cr(III) could alter the absorbance response of the Zn(II)-DDTC system. At a fixed Zn(II) concentration of 25 mg/L, the absorbance was 0.526245 in the absence of

Cr(III). The absorbance slightly decreased to 0.525625 at 5 mg/L Cr(III), but subsequently increased to 0.579840, 0.638470, 0.713945, and 0.805725 at Cr(III) concentrations of 10, 15, 20, and 25 mg/L, respectively.

The increasing absorbance response at higher Cr(III) concentrations indicates that the presence of Cr(III) was associated with a substantial change in the measured response of the Zn(II)-DDTC system. This observation is important because chromium can occur together with zinc in industrial wastewater and other contaminated environmental matrices (Wardhani, Wulan, Velda, Cahya, et al., 2024). Consequently, the analytical response obtained for Zn(II) cannot automatically be attributed exclusively to Zn(II) when other metal ions are present. One possible explanation is that Cr(III) can interact with DDTC under the experimental conditions and contribute to the absorbance measured at the selected wavelength. However, the present experiment was designed as a preliminary interference assessment and did not independently establish the mechanism responsible for the observed increase. Therefore, the increase in absorbance should be interpreted as evidence that Cr(III) affects the analytical response rather than as definitive proof of a specific Cr(III)-DDTC species or reaction mechanism.

The result has practical implications for application of the proposed method to environmental samples. Although UV-Vis spectrophotometry offers relatively simple instrumentation and accessibility compared with more sophisticated techniques, its selectivity depends strongly on the chemical reactions used to generate the analytical signal. The presence of coexisting metal ions may therefore affect the response and needs to be considered when applying the method to complex samples. Previous studies have likewise shown that DDTC-based extraction procedures may require appropriate control or masking of interfering metal ions to achieve reliable selectivity (Uddin, Salam, et al., 2013).

Overall, the preliminary Cr(III) experiment demonstrates an important limitation of the present Zn(II)-DDTC system: the absorbance response is affected by the presence of Cr(III). This finding does not invalidate the optimization of the Zn(II)-DDTC system, but it indicates that further selectivity studies are necessary before the method can be applied directly to real environmental samples. Future investigations should examine different Zn(II)/Cr(III) concentration ratios, evaluate other potentially interfering ions, and investigate whether masking or separation strategies can reduce the observed interference.

7. Overall Methodological Implications and Limitations

Taken together, the results establish a sequence of experimental conditions for the Zn(II)-DDTC-chloroform system, consisting of a maximum absorption wavelength of 335 nm, an optimum pH of 5, an optimum shaking time of 20 min, and a 50 min standing period based on the highest absorbance response observed. Under these conditions, the Zn(II) calibration curve showed a strong linear relationship over 10-40 mg/L with an R^2 value of 0.9988. These findings demonstrate that systematic optimization can establish the operational conditions required for the spectrophotometric measurement of the Zn(II)-DDTC complex. The study also provides a preliminary indication that the proposed system is not completely selective toward Zn(II) in the presence of Cr(III). Therefore, the main contribution of this work is not the establishment of a universally applicable zinc determination method, but the development and initial evaluation of an optimized Zn(II)-DDTC extraction-spectrophotometric system under controlled laboratory conditions.

Several limitations should be considered when interpreting these findings. First, the experiments were conducted using prepared metal-ion solutions rather than real environmental samples. Consequently, the behavior of the system in complex matrices containing multiple metal ions, organic matter, salts, and other constituents remains uncertain. Second, the interference study was limited to Cr(III), although industrial wastewater may contain several other potentially interfering species. Third, the analytical method was evaluated primarily through absorbance response and linearity; complete validation parameters such as accuracy, precision, recovery, detection limit, and quantification limit were not established in the present study. Finally, the preliminary Cr(III) experiment demonstrates an effect on absorbance but does not by itself establish the exact chemical mechanism responsible for that effect.

Future research should therefore extend the method to real wastewater samples and include comprehensive analytical validation. Further work should also investigate the selectivity of the method toward other metal ions, evaluate masking or separation procedures for Cr(III), and compare the proposed UV-Vis method with established instrumental techniques such as atomic absorption spectrometry or other elemental analysis methods. Such studies would clarify the practical applicability of the optimized Zn(II)-DDTC extraction system.

CONCLUSION

This study established an optimized extraction-spectrophotometric procedure for the determination of Zn(II) through formation of the Zn(II)-DDTC complex and extraction into chloroform. The Zn(II)-DDTC system exhibited a maximum absorption wavelength at 335 nm, while the optimum pH and shaking time were 5 and 20 min, respectively. The highest absorbance response during the stability evaluation was obtained after a standing period of 50 min. Under these optimized conditions, the Zn(II) calibration curve showed a strong linear relationship over the concentration range of 10-40 mg/L, with a regression equation of $y = 0.019x + 0.0551$ and an R^2 value of 0.9988. The findings demonstrate that systematic control of wavelength, pH, shaking time, and standing time is important for obtaining a consistent analytical response from the Zn(II)-DDTC-chloroform system. The study therefore provides an initial methodological basis for UV-Vis spectrophotometric determination of Zn(II) using DDTC and liquid-liquid extraction. However, the preliminary interference experiment showed that increasing Cr(III) concentrations generally increased the measured absorbance response, indicating that the proposed system is affected by the presence of Cr(III) under the investigated conditions.

Further research is recommended to validate the analytical performance of the proposed method through evaluation of accuracy, precision, recovery, detection limit, and quantification limit. Future studies should also investigate real environmental samples, examine interference from other metal ions, and develop suitable masking or separation procedures to minimize the effect of Cr(III). These additional investigations are necessary to establish the selectivity and practical applicability of the Zn(II)-DDTC UV-Vis method for environmental analysis.

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