

EXTRACTION BEHAVIOUR, EQUILIBRIUM CHARACTERISTICS, AND COMPLEXATION MECHANISM OF Cu(II), Ni(II), AND Co(II) WITH BIS(SALICYLALDEHYDE)ETHYLENEDIAMINE (SALEN) IN CHLOROFORM

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Abstract—The extraction behaviour, equilibrium characteristics, and complexation mechanism of Cu(II), Ni(II), and Co(II) using bis(salicylaldehyde)ethylenediamine (Salen) in chloroform were investigated under varying pH, equilibration time, mineral acid type, and acid concentration. Metal extraction was monitored by UV–Visible spectrophotometry. Maximum extraction occurred at pH 8 for Cu(II) and Ni(II), and pH 6 for Co(II). Under these optimum pH conditions, equilibrium was attained within 5 min for Ni(II), with an extraction value of 0.38, while Cu(II) and Co(II) reached equilibrium at 10 min, with extraction values of 0.24 and 0.32, respectively. In 10^{-4} M HCl, equilibrium extraction values of 20.0, 18.2 and 18.9 were obtained for Cu(II), Ni(II) and Co(II), respectively, whereas in 10^{-4} M H₂SO₄, Cu(II) and Co(II) both reached 20.0, compared with 16.1 for Ni(II). In perchloric acid, equilibrium extraction values were 19.8 for Cu(II), 18.2 for Ni(II), and 18.0 for Co(II), while nitric acid produced equilibrium values of 18.5, 13.1 and 20.0, respectively. At low acid concentrations (10^{-4} – 10^{-3} M), extraction was generally high; Co(II) extraction reached approximately 95% in nitric acid, but extraction decreased progressively with increasing acid concentration. Overall, Cu(II) generally exhibited the strongest extraction response, followed by Ni(II) and Co(II) under most conditions. The findings demonstrate that Salen–chloroform provides a rapid and effective system for transition-metal extraction, with extraction efficiency strongly dependent on pH, acid composition, and acid concentration.

Index Terms—Bis(salicylaldehyde)ethylenediamine, Salen ligand, solvent extraction, Cu(II), Ni(II), Co(II), Schiff base, metal complexation, chloroform

I. INTRODUCTION

The selective separation and determination of transition metal ions remain important challenges in analytical chemistry due to their extensive applications in environmental monitoring, metallurgical processing, pharmaceutical manufacturing, catalysis, and industrial quality control [1], [2]. Copper(II), nickel(II), and cobalt(II) are among the most significant first-row transition metals because of their essential roles in biological systems and their widespread industrial applications. However, excessive accumulation of these metals may pose environmental and health risks, requiring sensitive and reliable techniques for their separation and quantification [3].

Among available separation techniques, liquid–liquid solvent extraction remains one of the most widely employed methods because of its operational simplicity, rapid phase separation, high selectivity, and compatibility with spectrophotometric and instrumental analytical techniques [4]. The efficiency of solvent extraction depends on several factors, including metal–ligand complex stability, aqueous phase composition, solution acidity, extracting solvent polarity, ligand concentration, and equilibration conditions [5]. Schiff base compounds have received considerable attention as metal extractants because of their excellent coordination properties arising from nitrogen and oxygen donor atoms. These ligands readily form stable chelate complexes with transition metal ions and have found applications in analytical chemistry, catalysis, separation science, and coordination chemistry [6], [7]. Bis(salicylaldehyde)ethylenediamine (Salen) is a tetradentate Schiff base ligand containing two phenolic oxygen atoms and two azomethine nitrogen atoms capable of

coordinating divalent metal ions through multiple donor sites. The ligand forms stable neutral complexes with transition metals, which possess high solubility in non-polar organic solvents such as chloroform, thereby making Salen a suitable extractant for metal separation processes [8], [9].

The coordination chemistry of Salen complexes has been extensively studied, particularly in catalysis and molecular materials; however, systematic investigations of the extraction behaviour, equilibrium properties, and extraction mechanism of Cu(II), Ni(II), and Co(II) using Salen in chloroform remain comparatively limited. Understanding the factors controlling metal transfer between aqueous and organic phases is essential for optimizing separation efficiency and developing selective extraction procedures. Therefore, this study investigated the solvent extraction behaviour of Cu(II), Ni(II), and Co(II) using bis(salicylaldehyde)ethylenediamine in chloroform. The effects of solution pH, contact time, mineral acid type, and acid concentration were evaluated. Furthermore, equilibrium characteristics and complexation behaviour were examined to establish the mechanism responsible for metal ion extraction.

II. MATERIALS AND METHODS

A. Chemicals and Reagents

All chemicals used in this study were of analytical reagent grade and were used without further purification. Bis(salicylaldehyde)ethylenediamine (Salen) was synthesized according to the standard Schiff base condensation method described by Vogel [10]. The synthesized ligand was dissolved in absolute ethanol to prepare a 0.5% (w/v) Salen solution. Chloroform (CHCl₃) was used as the organic extraction phase due to its ability to dissolve neutral metal–chelate complexes. Stock solutions of Cu(II), Ni(II), and Co(II)

(1.0 mg mL⁻¹) were prepared from appropriate analytical-grade metal salts using distilled deionized water. Working solutions were prepared by suitable dilution immediately before use. Hydrochloric acid (HCl), sulfuric acid (H₂SO₄), nitric acid (HNO₃), and perchloric acid (HClO₄) solutions were freshly prepared by dilution of concentrated analytical-grade acids. Buffer solutions covering the required pH range were prepared according to standard procedures [10].

B. Solvent Extraction Procedure

Liquid-liquid extraction experiments were performed at room temperature (25 ± 2 °C). Equal volumes (5 mL each) of aqueous metal solution and chloroform containing 0.5% (w/v) Salen were transferred into extraction vessels. The mixtures were mechanically shaken for predetermined contact times to achieve equilibrium. After equilibration, the aqueous and organic phases were allowed to separate completely. The residual metal concentration in the aqueous phase was determined spectrophotometrically, while the amount transferred into the organic phase was calculated by difference between the initial and final aqueous concentrations.

C. Effect of Solution pH on Metal Extraction

The influence of aqueous phase pH on the extraction efficiency of Cu(II), Ni(II), and Co(II) was investigated using buffered solutions. Aliquots of metal ion solutions were adjusted to the desired pH values using appropriate buffer systems, followed by extraction with 5 mL chloroform containing 0.5% (w/v) Salen. After equilibration at the optimum contact time, the phases were separated and the remaining metal ion concentration in the aqueous phase was determined spectrophotometrically. The percentage extraction was calculated using Equation (1):

$$\%E = \frac{C_i - C_f}{C_i} \times 100 \quad (1)$$

where C_i and C_f represent the initial and final concentrations of the metal ion in the aqueous phase, respectively.

D. Effect of Mineral Acid Medium

The effect of mineral acid composition on extraction behaviour was evaluated using hydrochloric acid (HCl), sulfuric acid (H₂SO₄), nitric acid (HNO₃), and perchloric acid (HClO₄). The hydrogen ion concentration was varied over a broad range to investigate the influence of acidity on metal-ligand complex formation. For each experiment, the required volume of acid solution was added to the metal ion solution before extraction with Salen-containing chloroform. The extraction efficiency was determined after phase separation using the procedure described above.

E. Extraction Kinetics and Equilibrium Time

The effect of contact time on extraction efficiency was studied by varying the shaking time from 1 to 15 min. Samples were collected at 1, 3, 5, 10, and 15 min intervals. The equilibrium extraction time was defined as the minimum period required to achieve maximum extraction efficiency without further significant increase.

F. Spectrophotometric Determination of Metal Ions

The absorption spectra of the extracted metal complexes were recorded using a UV-Visible spectrophotometer. Quantitative determination was carried out at the wavelength of maximum absorption for each metal complex: 395 nm for Cu(II), 425 nm for Ni(II), and 400 nm for Co(II). Calibration curves were prepared using standard metal ion solutions under identical analytical conditions. All measurements were performed in triplicate, and the mean values were used for subsequent calculations.

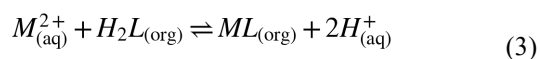
G. Distribution Ratio and Extraction Equilibrium

The distribution ratio (D) was calculated according to Equation (2):

$$D = \frac{[M]_{\text{org}}}{[M]_{\text{aq}}} \quad (2)$$

where $[M]_{\text{org}}$ and $[M]_{\text{aq}}$ represent the equilibrium concentrations of metal ions in the organic and aqueous phases, respectively.

The extraction equilibrium of divalent metal ions by Salen may be represented as:



where H_2L represents the protonated Salen ligand and ML represents the neutral metal-Salen complex.

The extraction constant (K_{ex}) was determined from the equilibrium relationship:

$$K_{\text{ex}} = \frac{[ML]_{\text{org}}[H^+]^2}{[M^{2+}]_{\text{aq}}[H_2L]_{\text{org}}} \quad (4)$$

H. Determination of Metal-Ligand Stoichiometry

The stoichiometric composition of the extracted complexes was determined using Job's continuous variation method. Equimolar solutions of the metal ions and Salen ligand were mixed in varying proportions while maintaining a constant total concentration. The absorbance of each extracted complex was measured at its corresponding maximum absorption wavelength. The position of the maximum absorbance in the Job's plot was used to determine the metal-to-ligand ratio.

I. Statistical Analysis

All experiments were conducted in triplicate, and results are expressed as mean ± standard deviation. Statistical analysis was performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). One-way analysis of variance (ANOVA) was used to determine significant differences among extraction conditions. Differences were considered statistically significant at $p < 0.05$.

III. RESULTS

A. Stability of Salen Reagent and Metal Ion Solutions

The stability of the prepared Salen reagent and metal ion solutions was evaluated before the extraction experiments. The Salen solution prepared in ethanol remained clear and stable throughout the experimental period, with no visible

precipitation, colour change, or evidence of decomposition. Similarly, the Cu(II), Ni(II), and Co(II) stock solutions maintained their initial appearance and showed no observable instability during storage and experimental application. The buffer solutions and mineral acid solutions prepared for extraction experiments also remained stable throughout the study period. The observed stability of all reagents ensured that variations in extraction efficiency resulted from changes in experimental conditions rather than reagent deterioration.

B. Effect of Solution pH on the Extraction of Cu(II), Ni(II), and Co(II)

The extraction efficiency of Cu(II), Ni(II), and Co(II) using 0.5% (w/v) bis(salicylaldehyde)ethylenediamine (Salen) in chloroform was investigated over a range of pH values. The effect of pH on metal ion extraction is presented in Fig. 1. The extraction behaviour of the three metal ions varied with changes in solution pH. At the lower pH range investigated, the extraction efficiencies of Cu(II), Ni(II), and Co(II) were relatively low. Progressive increases in extraction efficiency were observed as the pH of the aqueous phase increased. Copper(II) extraction increased steadily with increasing pH and reached its maximum extraction at pH 8. Nickel(II) showed a similar trend, with maximum extraction also achieved at pH 8. In contrast, Co(II) attained maximum extraction at a lower pH value of 6. Among the investigated metal ions, Cu(II) displayed the highest extraction response across most of the investigated pH range, followed by Ni(II) and Co(II). Beyond the optimum pH values, further increases in pH did not produce additional improvement in extraction efficiency.

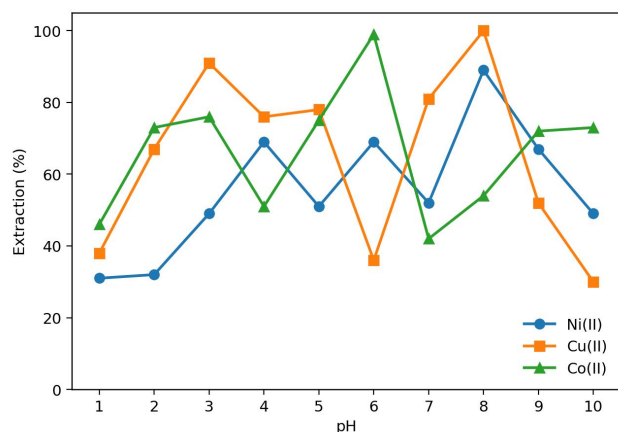


Fig. 1. Effect of solution pH on the extraction of Cu(II), Ni(II), and Co(II) using 0.5% (w/v) bis(salicylaldehyde)ethylenediamine (Salen) in chloroform.

C. Effect of Contact Time on Extraction Efficiency under Optimum pH Conditions

The effect of equilibration time on the extraction of Cu(II), Ni(II), and Co(II) was investigated under the optimum pH conditions identified from the pH study. The extraction values obtained at different contact times are presented in Table I. Extraction efficiency increased with increasing contact time for all investigated metal ions. For Co(II), extraction increased

from 0.12 at 1 min to 0.32 at 10 min. No further increase was observed after extending the contact time to 15 min.

Nickel(II) exhibited a faster extraction response compared with the other metals. Extraction increased from 0.28 at 1 min to 0.38 at 5 min, after which the value remained constant up to 15 min. Copper(II) showed a gradual increase in extraction efficiency, increasing from 0.14 at 1 min to 0.24 at 10 min. Similar to Co(II) and Ni(II), no further increase occurred after equilibrium was reached. The equilibrium extraction values obtained were 0.32 for Co(II), 0.38 for Ni(II), and 0.24 for Cu(II). The results indicated that the required equilibration period depended on the individual metal ion.

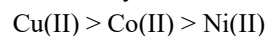
TABLE I
EXTRACTION OF Cu(II), Ni(II), AND Co(II) FROM BUFFERED SOLUTIONS AT DIFFERENT CONTACT TIMES USING 0.5% (w/v) SALEN IN CHLOROFORM

Contact time (min)	Co(II) (pH 6)	Ni(II) (pH 8)	Cu(II) (pH 8)
1	0.12	0.28	0.14
3	0.14	0.35	0.19
5	0.22	0.38	0.23
10	0.32	0.38	0.24
15	0.32	0.38	0.24

Initial metal concentration = 20 µg per 5 mL aqueous phase.

D. Effect of Hydrochloric Acid Medium on Extraction Behaviour

The extraction behaviour of Cu(II), Ni(II), and Co(II) from hydrochloric acid medium was investigated at a hydrogen ion concentration of 10^{-4} M. The effect of contact time on extraction efficiency is presented in Table II. All investigated metal ions showed increased extraction with increasing contact time. Copper(II) exhibited the highest extraction efficiency throughout the experimental period. At 1 min, Cu(II) extraction was 16.5, which increased to 20.0 after 5 min and remained constant until 15 min. Nickel(II) extraction increased from 11.1 at 1 min to 18.2 at 10 min. Cobalt(II) showed the largest increase during extraction, rising from 5.1 at 1 min to 18.9 at 10 min. At equilibrium conditions (10–15 min), the extraction order in hydrochloric acid medium was:



No further increase in extraction values was observed after 10 min for any of the investigated metals.

TABLE II
EXTRACTION OF Cu(II), Ni(II), AND Co(II) FROM HYDROCHLORIC ACID SOLUTION AT DIFFERENT CONTACT TIMES ($[\text{H}^+] = 10^{-4}$ M)

Contact time (min)	Co(II)	Ni(II)	Cu(II)
1	5.1	11.1	16.5
3	10.2	16.3	17.6
5	18.0	18.0	20.0
10	18.9	18.2	20.0
15	18.9	18.2	20.0

E. Effect of Sulfuric Acid Medium on Extraction Behaviour

The extraction behaviour of Cu(II), Ni(II), and Co(II) from sulfuric acid medium was investigated at a hydrogen ion

concentration of 10^{-4} M. The influence of contact time on extraction efficiency is presented in Table III. The extraction efficiency of all three metal ions increased with increasing contact time, although differences were observed in the magnitude of extraction. Copper(II) exhibited relatively high extraction throughout the experiment, with extraction increasing from 18.0 at 1 min to 20.0 at 10 min. The extraction value remained unchanged at 15 min. Cobalt(II) showed a progressive increase in extraction efficiency, increasing from 13.5 at 1 min to 20.0 at 10 min. This value remained constant after further extension of the contact time to 15 min. Nickel(II) exhibited a slower increase compared with Cu(II) and Co(II). The extraction value increased from 14.6 at 1 min to 16.1 at 10 min and remained unchanged thereafter. At equilibrium conditions (10–15 min), Cu(II) and Co(II) recorded similar extraction values (20.0), whereas Ni(II) showed a lower extraction value (16.1). The equilibrium extraction order in sulfuric acid medium was:

$$\text{Cu(II)} \approx \text{Co(II)} > \text{Ni(II)}$$

TABLE III
EXTRACTION OF Cu(II), Ni(II), AND Co(II) FROM SULFURIC ACID SOLUTION AT DIFFERENT CONTACT TIMES ($[\text{H}^+] = 10^{-4}$ M)

Contact time (min)	Co(II)	Ni(II)	Cu(II)
1	13.5	14.6	18.0
3	15.1	15.5	18.0
5	16.5	16.0	18.3
10	20.0	16.1	20.0
15	20.0	16.1	20.0

F. Effect of Perchloric Acid Medium on Extraction Behaviour

The extraction of Cu(II), Ni(II), and Co(II) from perchloric acid medium at a hydrogen ion concentration of 10^{-4} M is presented in Table IV. The extraction values increased with increasing contact time for all metal ions. Copper(II) demonstrated the highest extraction efficiency throughout the contact period. The extraction value increased from 12.2 at 1 min to 19.8 at 10 min, after which no further increase was recorded. Nickel(II) extraction increased steadily from 8.1 at 1 min to 18.2 at 10 min and remained constant at 15 min. Cobalt(II) showed the most significant increase during the initial extraction period, increasing from 0.15 at 1 min to 16.3 at 3 min, followed by a gradual increase to 18.0 at 10 min. At equilibrium, Cu(II) exhibited the highest extraction value (19.8), followed by Ni(II) (18.2) and Co(II) (18.0). The extraction values remained unchanged between 10 and 15 min. The equilibrium extraction order in perchloric acid medium was:

$$\text{Cu(II)} > \text{Ni(II)} > \text{Co(II)}$$

TABLE IV
EXTRACTION OF Cu(II), Ni(II), AND Co(II) FROM PERCHLORIC ACID SOLUTION AT DIFFERENT CONTACT TIMES ($[\text{H}^+] = 10^{-4}$ M)

Contact time (min)	Co(II)	Ni(II)	Cu(II)
1	0.15	8.1	12.2
3	16.3	14.0	16.3

Contact time (min)	Co(II)	Ni(II)	Cu(II)
5	17.1	16.7	19.6
10	18.0	18.2	19.8
15	18.0	18.2	19.8

G. Effect of Nitric Acid Medium on Extraction Behaviour

The extraction behaviour of Cu(II), Ni(II), and Co(II) from nitric acid medium was investigated at a hydrogen ion concentration of 10^{-4} M. The effect of contact time on extraction efficiency is presented in Table V. Cobalt(II) exhibited a rapid increase in extraction efficiency during the extraction period. The extraction value increased from 8.5 at 1 min to 19.9 at 5 min and reached a maximum value of 20.0 after 10 min. Copper(II) showed comparatively high extraction throughout the experiment, increasing from 16.1 at 1 min to 18.5 at 10 min. Nickel(II) exhibited the lowest extraction response, increasing from 6.5 at 1 min to 13.1 at 10 min. At equilibrium conditions, Co(II) showed the highest extraction value (20.0), followed by Cu(II) (18.5) and Ni(II) (13.1). The extraction values remained essentially unchanged after 10 min.

TABLE V
EXTRACTION OF Cu(II), Ni(II), AND Co(II) FROM NITRIC ACID SOLUTION AT DIFFERENT CONTACT TIMES ($[\text{H}^+] = 10^{-4}$ M)

Contact time (min)	Co(II)	Ni(II)	Cu(II)
1	8.5	6.5	16.1
3	14.0	12.8	17.3
5	19.9	12.7	18.4
10	20.0	13.1	18.5
15	20.0	13.0	18.4

H. Effect of Mineral Acid Concentration on Co(II) Extraction

The influence of mineral acid concentration on the extraction of Co(II) using 0.5% (w/v) Salen in chloroform is shown in Fig. 2. Extraction efficiency was evaluated across different concentrations of hydrochloric acid, sulfuric acid, nitric acid, and perchloric acid. At low acid concentrations (10^{-4} – 10^{-3} M), high extraction efficiencies were observed in all investigated acid media. Nitric acid produced the highest extraction response at the lowest concentration, with approximately 95% extraction. Hydrochloric acid also showed high Co(II) extraction within the dilute acid range. As the acid concentration increased, Co(II) extraction decreased progressively in all acid systems. The reduction in extraction became more pronounced at higher acid concentrations. Perchloric acid exhibited the lowest extraction efficiency throughout most of the concentration range investigated.

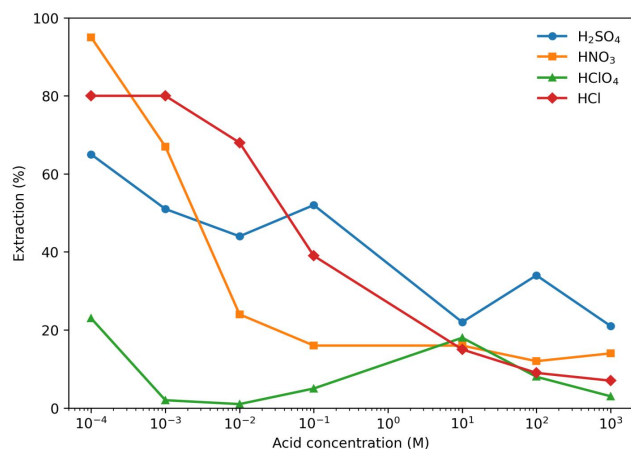


Fig. 2. Effect of mineral acid concentration on the extraction of Co(II) using 0.5% (w/v) bis(salicylaldehyde)ethylenediamine (Salen) in chloroform.

I. Effect of Mineral Acid Concentration on Ni(II) Extraction

The effect of mineral acid concentration on Ni(II) extraction is presented in Fig. 3. Extraction efficiency varied according to both acid type and acid concentration. At low acid concentrations, Ni(II) showed relatively high extraction values in all investigated media. Hydrochloric acid and sulfuric acid maintained higher extraction values compared with nitric acid and perchloric acid. Increasing acid concentration resulted in a progressive decline in Ni(II) extraction. The decrease was more evident at higher acid concentrations, where extraction efficiencies became substantially reduced.

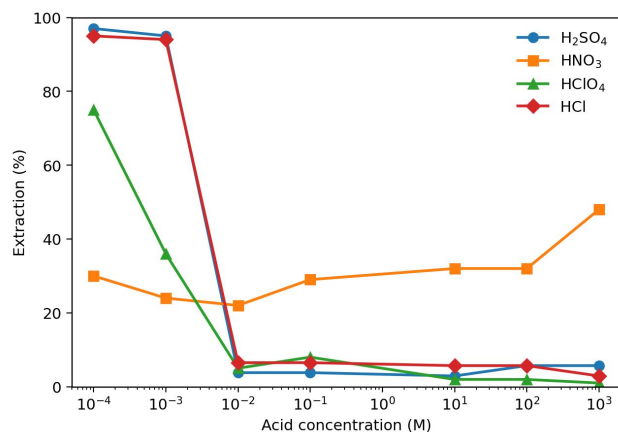


Fig. 3. Effect of mineral acid concentration on the extraction of Ni(II) using 0.5% (w/v) bis(salicylaldehyde)ethylenediamine (Salen) in chloroform.

J. Effect of Mineral Acid Concentration on Cu(II) Extraction

The effect of mineral acid concentration on Cu(II) extraction using Salen in chloroform is presented in Fig. 4. Copper(II) showed high extraction efficiencies at low acid concentrations (10^{-4} – 10^{-3} M) in all investigated acid media. The highest extraction responses were observed in hydrochloric acid and nitric acid systems. With increasing acid concentration, Cu(II) extraction gradually decreased. The reduction was observed across all mineral acid systems, with

the lowest extraction values occurring at the highest acid concentrations investigated.

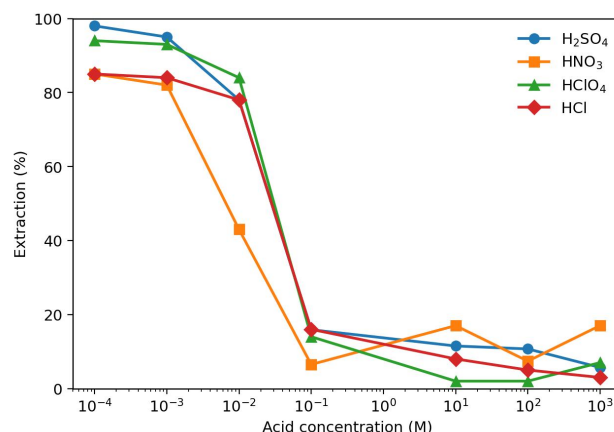


Fig. 4. Effect of mineral acid concentration on the extraction of Cu(II) using 0.5% (w/v) bis(salicylaldehyde)ethylenediamine (Salen) in chloroform.

IV. DISCUSSION

The present study demonstrated that bis(salicylaldehyde)ethylenediamine (Salen) dissolved in chloroform is an effective extractant for the separation of Cu(II), Ni(II), and Co(II) ions from aqueous media. The extraction behaviour of the investigated metal ions was strongly dependent on solution pH, equilibration time, mineral acid composition, and acid concentration. These parameters influence the availability of ligand donor atoms, the stability of the metal–ligand complexes, and the distribution of the extracted species between aqueous and organic phases.

Salen is a tetradentate Schiff base ligand containing two phenolic oxygen atoms and two azomethine nitrogen atoms capable of coordinating transition metal ions. The formation of stable metal–Salen complexes has been widely reported due to the strong chelating ability of the ligand and its ability to stabilize divalent transition metal ions through N_2O_2 donor coordination [8], [9]. The neutral character and high organic-phase solubility of these complexes facilitate their transfer into non-polar solvents such as chloroform, making Salen suitable for liquid–liquid extraction applications.

A. Influence of Solution pH on Metal Extraction

The extraction efficiency of Cu(II), Ni(II), and Co(II) increased with increasing pH, with maximum extraction occurring at pH 8 for Cu(II) and Ni(II), and pH 6 for Co(II). This behaviour is consistent with the general principles governing chelate extraction, where ligand deprotonation enhances the coordination ability of donor atoms and promotes the formation of extractable neutral metal complexes. At low pH values, the extraction process is reduced because the donor atoms of Schiff base ligands undergo protonation, decreasing their ability to coordinate metal ions. As the pH increases, progressive deprotonation of the phenolic hydroxyl groups allows stronger interaction between the ligand and metal ions, resulting in enhanced complex formation and increased extraction into the organic phase [4], [5]. The different optimum pH values observed among the investigated

metals reflect differences in their complexation behaviour. Copper(II) and nickel(II) required more alkaline conditions for maximum extraction, whereas cobalt(II) achieved optimum extraction at a lower pH. Similar differences in pH-dependent extraction behaviour among first-row transition metals have been reported for Schiff base and oxygen–nitrogen donor extractants [4], [12]. Copper(II) exhibited the highest extraction response over a wide pH range. This observation agrees with the strong affinity of Cu(II) for tetradentate Schiff base ligands. Cu(II) commonly forms highly stable square-planar or distorted octahedral complexes with N₂O₂ donor ligands because of favourable electronic configuration and ligand-field stabilization effects [9].

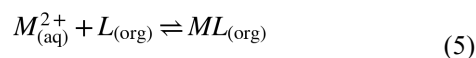
B. Effect of Equilibration Time on Extraction Efficiency

The extraction kinetics showed that equilibrium was attained within 5–10 min for the investigated metal ions. Rapid attainment of equilibrium is an important characteristic of efficient solvent extraction systems because it reduces analytical processing time and improves reproducibility. Nickel(II) achieved equilibrium within 5 min, whereas Cu(II) and Co(II) required approximately 10 min. The variation in equilibration time may be associated with differences in the rate of complex formation and the interaction between each metal ion and the Salen ligand. Previous studies on metal chelate extraction have shown that extraction kinetics depend on metal ion characteristics, ligand structure, solvent properties, and interfacial mass transfer processes [4], [12].

The rapid extraction observed in the present study indicates efficient transfer of the metal–Salen complexes from the aqueous phase into chloroform. Similar rapid extraction behaviour has been reported for neutral chelate extraction systems involving Schiff base ligands [5].

C. Influence of Mineral Acid Media on Metal Extraction

The extraction behaviour of Cu(II), Ni(II), and Co(II) varied significantly among hydrochloric, sulfuric, nitric, and perchloric acid media. The observed differences indicate that the nature of the aqueous acid phase plays an important role in controlling metal extraction efficiency. Higher extraction efficiencies were generally obtained at low acid concentrations, whereas increasing acid concentration resulted in reduced extraction for all investigated metals. This behaviour is characteristic of neutral chelate extraction systems, where excessive acidity reduces the availability of ligand donor sites through proton competition. According to solvent extraction theory, the extraction equilibrium of a neutral metal chelate can be represented as:



Increasing hydrogen ion concentration shifts this equilibrium by reducing the concentration of available ligand species capable of coordinating metal ions [4].

The mineral acid type also affected extraction efficiency. Hydrochloric and sulfuric acid media generally supported higher extraction compared with perchloric acid, while nitric acid produced distinct extraction patterns depending on the metal ion. Differences among acid media can arise from

variations in ionic strength, metal–anion interactions, and aqueous speciation effects [5].

D. Comparative Extraction Behaviour of Cu(II), Ni(II), and Co(II)

Among the three investigated transition metals, Cu(II) generally showed superior extraction efficiency, followed by Ni(II) and Co(II) under most experimental conditions. The enhanced extraction of Cu(II) can be attributed to its strong coordination preference toward tetradentate Schiff base ligands.

Salen-type ligands are particularly effective for Cu(II) because copper complexes commonly exhibit high thermodynamic stability and favourable geometric compatibility with the N₂O₂ donor environment of Salen ligands [9]. The strong Cu(II)–Salen interaction has also contributed to the extensive application of copper–Salen complexes in catalysis, molecular materials, and coordination chemistry.

Nickel(II) also forms stable complexes with Salen due to its ability to adopt square-planar and octahedral coordination environments. However, the extraction efficiency may differ from Cu(II) because of differences in ionic radius, ligand-field stabilization, and complex formation constants [8]. Cobalt(II) showed comparatively variable extraction behaviour depending on the aqueous conditions. The lower extraction efficiency under some conditions may be related to differences in complex stability and aqueous speciation compared with Cu(II) and Ni(II). The extraction behaviour observed in this study supports a neutral chelate extraction mechanism involving coordination between metal ions and Salen molecules. The ligand coordinates through two nitrogen atoms and two phenolic oxygen atoms to produce neutral metal complexes soluble in chloroform. The dependence of extraction efficiency on pH and acid concentration confirms that proton availability strongly influences the formation of the extractable complex. Similar mechanisms have been reported for Schiff base extractants and neutral chelating agents used in transition metal separation [4], [12].

V. CONCLUSION

The present study demonstrated the effectiveness of bis(salicylaldehyde)ethylenediamine (Salen) dissolved in chloroform as a chelating extractant for the separation of Cu(II), Ni(II), and Co(II) from aqueous solutions. The extraction behaviour of the investigated metal ions was strongly influenced by solution pH, equilibration time, mineral acid composition, and acid concentration. Maximum extraction was achieved at pH 8 for Cu(II) and Ni(II), while Co(II) showed optimum extraction at pH 6. The extraction process reached equilibrium rapidly, requiring 5 min for Ni(II) and 10 min for Cu(II) and Co(II). Mineral acid studies revealed that extraction efficiency was strongly dependent on both acid concentration and acid type, with higher extraction efficiencies generally observed at lower acid concentrations. The results confirmed that Cu(II), Ni(II), and Co(II) form stable extractable complexes with Salen in chloroform, with Cu(II) generally exhibiting the highest extraction efficiency

under most investigated conditions. The observed dependence of extraction efficiency on pH and acidity highlights the importance of controlling aqueous conditions for effective metal recovery and separation.

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