

Obtaining the Zinc Ammine Carbonate, Hydrozincite, and Zinc Oxide from Dolomite-Containing Smithsonite Ore by Hydrometallurgical Methods

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Abstract

In this study, the effects of ammonia concentration and solid/liquid ratio on the dissolution behavior of zinc from local dolomite-containing smithsonite (ZnCO_3) ore samples in aqueous ammonia solutions were investigated at room temperature by X-ray fluorescence (XRF), X-ray diffraction (XRD), and Fourier-transform infrared (FT-IR) spectroscopy analyses. The findings revealed a significant increase in the dissolution ratio of zinc, rising from 43.6% to 56.3% with an increase in ammonia concentration from 5.0 to 6.0 M. Subsequently, a maximum zinc dissolution ratio of 61.2% was achieved after dissolution in a 12 M NH_3 solution. The XRD pattern of the residue obtained after dissolution in 6.0 M NH_3 solution for 120 min, under a solid/liquid ratio of 0.15 g/mL (the optimized condition), indicated substantial dissolution of the smithsonite phase in the ore sample. At the same time, the gangue minerals, goethite, and dolomite, remained predominantly undissolved. This observation underscores the selectivity of ammonia solution for zinc dissolution. Concurrently, dissolution ratios of cadmium were also determined. In the second part of the study, precipitation tests were conducted on dissolved zinc, carbonate, and ammonia-containing pregnant solutions obtained after selected dissolution experiments. By complete evaporation of the pregnant solutions at low temperatures, i.e., 70°C, relatively pure solid zinc ammine carbonate ($\text{Zn}(\text{NH}_3)\text{CO}_3$) precipitates. At higher temperatures (i.e., 140-170°C), quite pure solid hydrozincite (i.e., zinc carbonate hydroxide $\text{Zn}_5(\text{CO}_3)_2(\text{OH})_6$) precipitates could be prepared. High-temperature heating of $\text{Zn}(\text{NH}_3)\text{CO}_3$ and $\text{Zn}_5(\text{CO}_3)_2(\text{OH})_6$ precipitates at 400°C generated single-phase zinc oxide (ZnO). The chemical compositions, FT-IR spectra, and scanning electron microscope (SEM) photographs of some of the precipitates were also presented.

Keywords

Ammonia dissolution, Smithsonite, Zinc ammine carbonate, Zinc carbonate hydroxide, Zinc Oxide



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Introduction

Zinc is the 23rd most abundant element in the Earth's crust and is the metal utilized in the highest amount after iron, aluminum, and copper. Zinc is obtained by extractive metallurgical methods (i.e., pyro-/hydro-/electro-metallurgy) from its primary sources. It is mainly used as a coating on steel to protect against corrosion by galvanizing, and it is also used as an alloying element for the production of alloys (brass, aluminum) and chemical compounds (zinc oxide, zinc sulfate) (ILZSG, 2020; Kania and Saternus, 2023; USGS, 2024).

Sulfide and non-sulfide zinc ores are crucial resources for zinc production. Historically, non-sulfide zinc ores were the primary source of Zn for centuries. However, their importance declined in the early 20th century with the advent of flotation and smelting techniques designed for zinc sulfide ores. Over the past few decades, zinc sulfide ores have become the dominant source of zinc metal production, accounting for more than 80% of the world's zinc output. Despite containing approximately 10 to 20% Zn, non-sulfide zinc ores have not been extensively mined in recent years due to the challenges associated with separating them from gangue and concentrating them using conventional flotation methods. However, in the last decades, the depletion of zinc sulfide ores, coupled with the development of new processing methods, such as solvent extraction and electrowinning, for non-sulfide zinc ores, has sparked renewed commercial interest in these ores. As a result, non-sulfide deposits are rapidly becoming an important source of metallic zinc. It is anticipated that, in the near future, the annual production of zinc from these ores could exceed rates of more than 10% of global zinc metal production (Hitzman et al., 2003; Gilg et al., 2008; Schneider et al., 2008; Abkhoshk et al., 2014).

In the literature, while there are many alkaline, i.e. sodium hydroxide, (Frenay, 1985; Zhao and Stanforth, 2000; Ghasemi and Azizi, 2018; Ehsani, Ucyildiz and Obut, 2019; Kumaş, Ehsani and Obut, 2020) or acidic (Frenay, 1985; Espiari, Rashchi and Sadrezaad, 2006; Deng et al., 2015; Wu et al., 2015; Feng et al., 2015; Abdel-Aal et al., 2016; Abalı, Bayca and Gümüş, 2017; Ghasemi and Azizi, 2017; Kaya and Serin Çakır, 2019) dissolution of oxidized zinc ores, containing smithsonite as the dominant zinc-containing mineral, the number of literature studies on ammonia dissolution is very limited (Frenay, 1985; Ehsani, Ehsani and Obut, 2021). Moreover, in the literature, which were not detailed and most of them were patent studies, materials such as zinc-containing ores, calcines, residues, etc. dissolved in ammoniacal or ammonium carbonate solutions, and generally from obtained pregnant solutions, the zinc compounds in basic zinc carbonate forms were obtained by physical precipitation methods (i.e., heating) (Ogden, 1932; Colton, 1938; Harvey, 2006; Moghaddam et al., 2014; López et al., 2017).

In this study, firstly, oxidized (carbonated) zinc (containing smithsonite mineral) ore obtained from the Kayseri region was dissolved with ammonia (containing ammonium ion) solutions. Following the dissolution process, solid-liquid separation was performed to obtain the pregnant solution. Then, the obtained pregnant solution was thermally treated at different temperatures. The precipitates are subjected to precipitation (heating/drying), and as a result of the process, relatively high zinc-content solids (mostly hydrozincite, hydrozincite / small amounts of zincamine carbonate mixture, or zinc oxide) are obtained. Following the precipitation (heating/drying) process, the precipitates will be subjected to calcination at a relatively high temperature (400 °C) to obtain highly pure zinc oxide.

Material and Methods

In this study, the experimental methods used by Ehsani et al. (2021) were generally followed in a similar manner for comparison purposes. Also, the ore sample used in this study was obtained from the Türkiye-Kayseri region, which has similarities with the ore used in previous studies (Kumaş, Ehsani and Obut, 2020).

The whole sample was subjected to size reduction (crushing, grinding, and sieving) in the Mining and Mineral Processing laboratories of Adana Alparslan Türkeş Science and Technology University. The material was then homogenized and kept in the laboratory for 10 days in order to be in balance with the humidity of the environment. It was then divided and placed in buckets for analysis and experiments.

Dissolution in ammonia solutions, solid/liquid separation, and precipitation (drying) processes were performed on the ground ore samples to obtain different zinc compounds. The dissolution experiments were carried out in glass beakers at room temperature using a heated magnetic stirrer. According to the results of previous studies, the stirring speed (600 rpm) and stirring time (120 minutes) remained constant and were not tested due to negligible effects on the dissolution rate. The ammonia concentration and solid/liquid ratio parameters in the dissolution experiments were 5-12 M NH₃ and 0.05-0.40 g solid/mL solution, respectively, and these values were determined through a few literature studies (Frenay, 1985; Ehsani, Ehsani and Obut, 2021) and preliminary tests. Glass beakers sealed with Parafilm® during the dissolution process to prevent ammonia evaporation. After dissolution, a glass funnel and filter paper were used for solid-liquid separation. Subsequently, solid-free pregnant solutions were used in precipitation experiments. The undissolved solids remaining on the filter were washed with water and dried in an oven at 105°C for 24 hours. The precipitation and drying processes were carried out in a stove (max. 210°C) for 24 hours.

Following the precipitation (heating/drying) process, the precipitates obtained were subjected to calcination in an oven at an elevated temperature (400 °C for 1 hour) to obtain highly pure zinc oxide (ZnO). Subsequently, X-ray diffraction (XRD; Rigaku miniflex 600) and X-ray fluorescence (XRF; Rigaku-Rigaku ZSX-Primus II) analyses were conducted on selected solids to identify both the ore sample and the final precipitates obtained from experimental studies. Scanning electron microscopy coupled with Energy Dispersive Spectroscopy (SEM-EDS; FEI Quanta 650; 20.00 kV) and Fourier transform infrared spectroscopy (FTIR-ATR; JASCO FT-IR 6800) analyses were performed on certain precipitates and solids resulting from calcination.

Results and Discussion

Characterization of the Ore Sample.

X-ray diffraction analysis of the ground ore sample revealed that the zinc-containing mineral in the ore was smithsonite (ZnCO_3) (ICDD-PDF no: 00-008-0449), while dolomite ($\text{CaMg}(\text{CO}_3)_2$) (ICDD-PDF number: 00-036-0426) was the most abundant gangue mineral, as shown in Fig. 1. Small amounts of other important gangue minerals such as quartz (SiO_2) (ICDD-PDF number: 00-4035-0063), goethite ($\text{Fe}(\text{OH})_2$) (ICDD-PDF number: 00-029-0713), and calcite were also detected. Since the characterization of the clay mineral present in the ore sample is not within the scope of this study, the type of clay mineral was not identified.

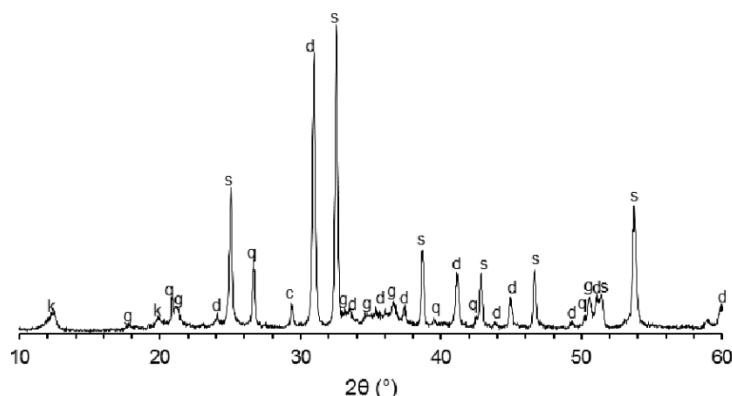


Fig. 1. The XRD pattern of the ore sample (s: smithsonite, c: calcite, d: dolomite, g: goethite, q: quartz, k: clay minerals)

The chemical composition of the ore sample determined by the X-ray fluorescence (XRF) method is presented in Table 1. Notably, alongside the substantial zinc content of the sample, the high carbon and minimal sulfur content affirm the presence of carbonated zinc minerals (i.e., smithsonite). The ore sample also contains significant amounts of iron, lead, and cadmium. The moisture content (105 °C, 2 hours) and loss on ignition (1000 °C, 20 minutes) values of the ore sample were determined as 1.1% and 28.5%, respectively.

Table 1. The chemical composition of the ore sample determined by the XRF method

Compound	ZnO	Fe_2O_3	SiO_2	Al_2O_3	PbO	Cd	C	S
%	21,2	11,7	18,2	9,87	0,51	0,07	5	0,04

The Fourier transform infrared (ATR-FTIR) spectrum of the original ore sample is shown in Fig. 2. The main characteristic absorption peak associated with smithsonite (ZnCO_3) is observed at approximately 744 cm^{-1} , known to be present in the composition of the ore sample by XRD analysis. This distinctive peak arises from the carbonate bonds (Huang and Kerr, 1960; Adler and Kerr, 1963) in the smithsonite, and does not overlap with the peaks of other components in the ore sample.

Furthermore, the characteristic peak of dolomite, the primary carbonate impurity in the ore sample, is observed at 728 cm^{-1} (Huang and Kerr, 1960; Weir and Lippincott, 1961; Adler and Kerr, 1963). Additionally, the spectrum peak value of the goethite ($\text{Fe}(\text{OH})_2$), one of the main impurities, is observed at approximately 798 cm^{-1} (Parida and Das, 1996; Ghosh et al., 2012). As a result, the XRD and ATR-FTIR analysis results of the original ore sample show compatibility with each other.

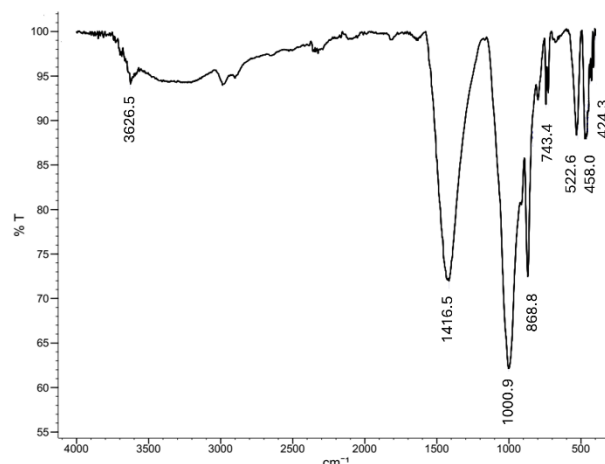
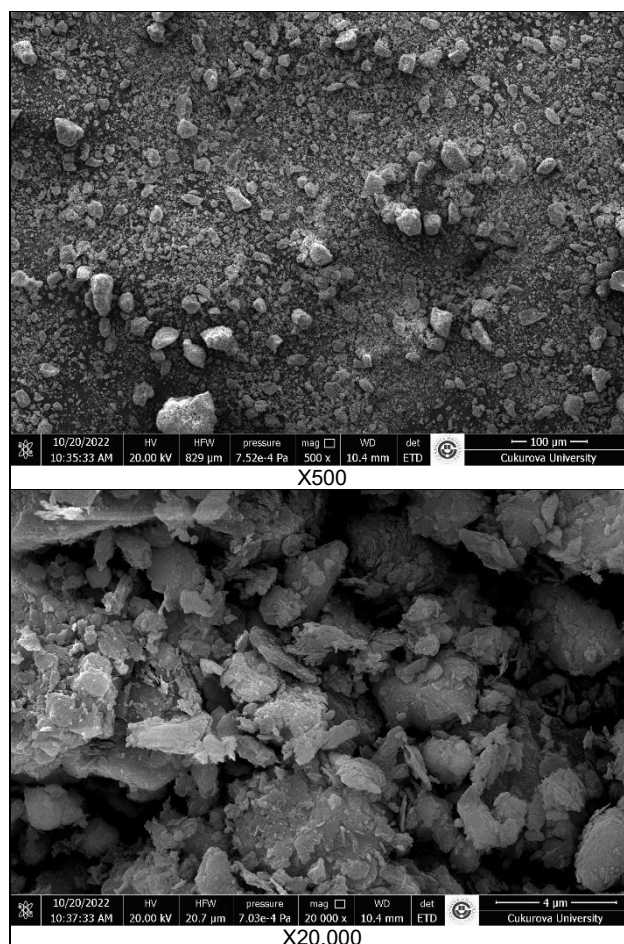


Fig 2. ATR-FTIR spectrum of the original ore sample.

Fig. 3 shows SEM images of the original ore sample at different magnification values (500, 20.000, and 40.000 magnification). As can be seen from Fig. 3, the particle size of most of the original ground ore sample is below 100 micrometers, which is consistent with the particle size distribution of the ground ore sample ($d_{80} = 135$ microns). There is also a significant proportion of the ore sample particles with a size below 10 microns. The sample is composed of angular and similarly shaped particles.



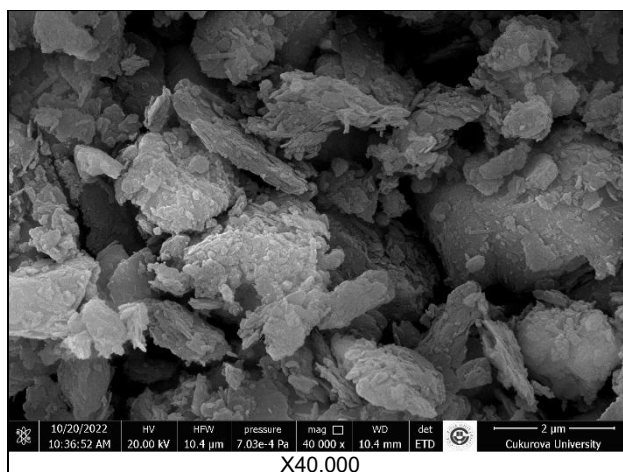
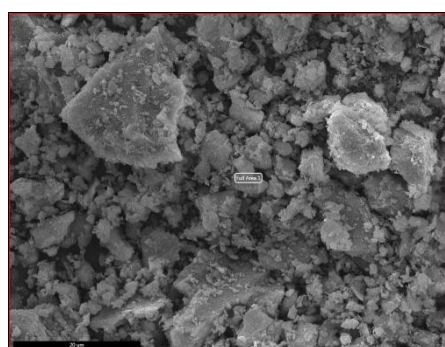


Fig. 3. SEM images of the original sample at different magnifications (X500, X20000, and X40,000)

SEM-EDS analysis of the original ore sample is shown in Fig. 4. As seen from the EDS analysis of the selected area of the ore sample, it is observed that the ore is a high-grade carbonated zinc ore (40.78% O, 13.4% C, 19% Zn). The ore sample is generally oxidized carbonate in structure, and the gangue minerals are mostly oxidized-carbonated forms of Fe, Mg, and Ca. This SEM-EDS analysis corroborates findings from XRD and XRF analyses, providing further support for the characterization of the ore sample. The consistency among these analytical techniques reinforces our understanding of the mineral composition and structure of the original ore sample.



Element	Weight %	Atomic %
C	13.4	23.91
O	40.78	54.63
Mg	7.5	6.62
Ca	7.95	4.25
Fe	11.38	4.37
Zn	19	6.23

Fig. 4. SEM-EDS analysis of the original ore sample

Dissolution Experiments.

The dissolution experiments were carried out in two series. In the first series, ammonia concentration was studied as a variable parameter. Following a comprehensive review of previous literature studies and preliminary experiments, the solid/liquid ratio and leaching time were determined as 0.15 g/mL and 120 minutes, respectively. The dissolution rate of zinc in the ore sample was then assessed across varying concentrations of ammonia (5, 6, 8, 10, and 12 M NH_3), with the results presented in Fig. 5.

As depicted in Fig. 5, the zinc dissolution rate exhibits a noticeable increase from 43.6% at 5 M NH_3 to 56.3% at 6 M NH_3 . However, at concentrations higher than 6 M NH_3 , the zinc dissolution rate curve becomes clearly horizontal, and the increase in dissolution rate appears to be negligible. At the highest ammonia concentration of 12 M NH_3 , the highest dissolution rate (61.2%) value was obtained. Therefore, considering the reagent (ammonia) consumption against the zinc dissolution rate, the optimal concentration appears to be 6 M NH_3 . This concentration provides a substantial increase in dissolution rate while minimizing excessive reagent usage.

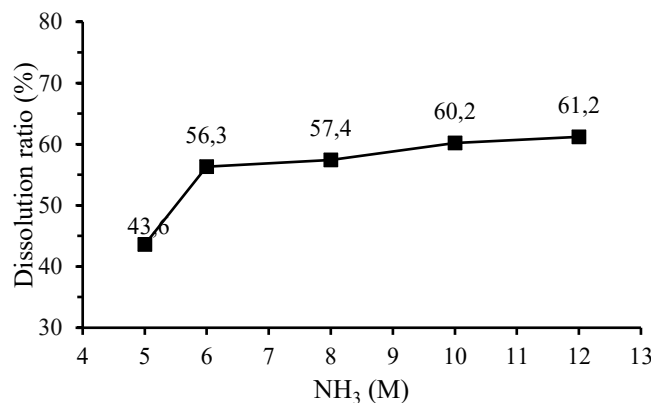


Fig 5. Dissolution behavior of zinc in the ore sample as a function of NH_3 concentration.

In Fig. 6, the XRD patterns of both the ore sample and the remaining solids at specified ammonia concentrations are illustrated. Notably, the intensities of all X-ray diffraction peaks corresponding to the smithsonite mineral decrease with increasing ammonia concentration. This trend signifies the gradual dissolution of the smithsonite (ZnCO_3) mineral within the ore sample upon exposure to ammonia solutions.

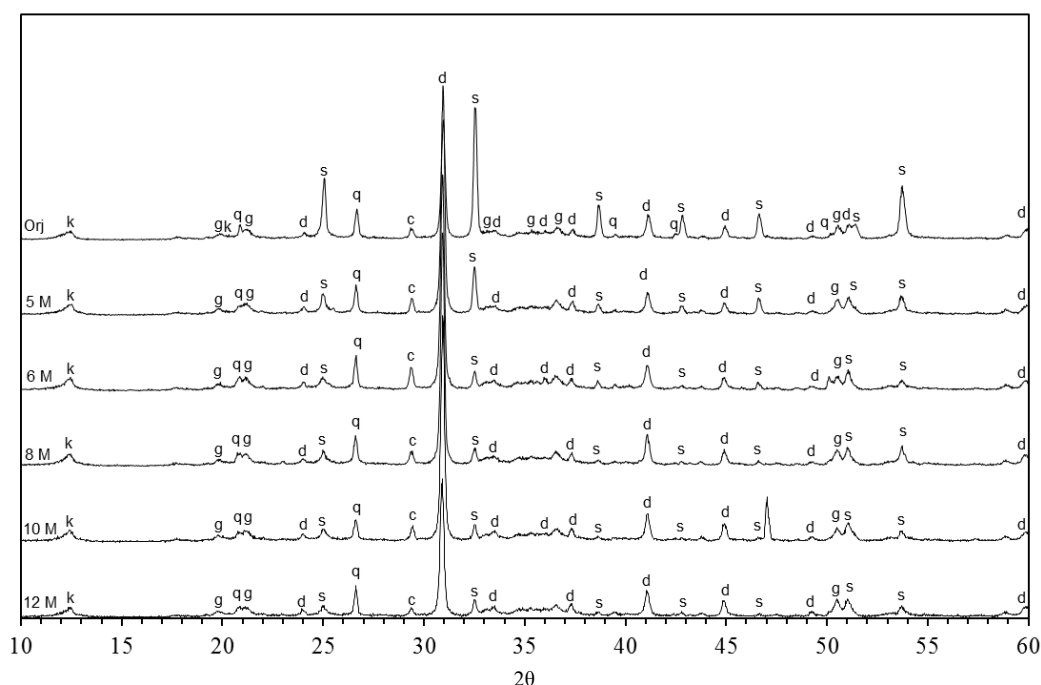


Fig. 6. XRD patterns of the ore sample (Orj) and the undissolved solids after dissolution at different ammonia concentrations (s: smithsonite, d: dolomite, c: calcite, q: quartz, g: goethite, k: clay minerals).

The XRD peaks corresponding to dolomite ($\text{CaMg}(\text{CO}_3)_2$) and goethite ($\text{Fe}(\text{OH})_2$), the main impurities in the ore sample, remain almost unchanged in the patterns of the undissolved solids, indicating that dissolution in ammonia solutions is a highly selective dissolution process in terms of zinc dissolution compared to dissolution in acidic solutions. This selectivity is also reported in the literature (Wang et al., 2008; Li et al., 2010; Ma et al., 2011; Ehsani, Ehsani, and Obut, 2021). In addition, the XRD peaks of quartz and clay minerals, which are other impurities in low amounts, remain almost unchanged after dissolution.

Furthermore, in the ATR-FTIR analysis of the residual solids (Fig. 7), the characteristic peaks of the main impurities, goethite (798 cm^{-1}) and dolomite (728 cm^{-1}), appear almost unchanged, i.e., largely unaffected by the dissolution process, in the spectra of the solids remaining undissolved, again indicating that the ammonia solution selectively dissolves smithsonite.

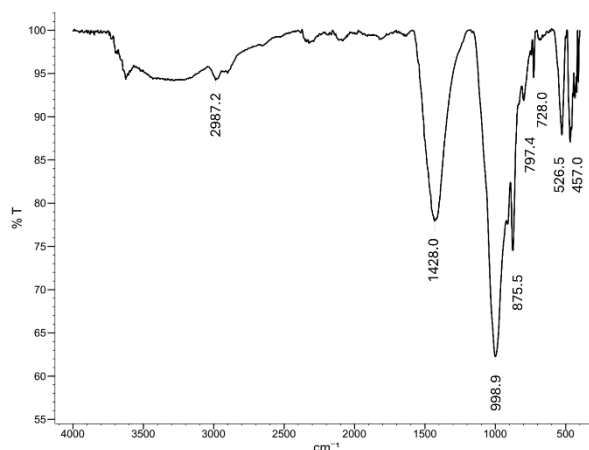


Fig. 7. ATR-FTIR spectrum of residual solid after dissolution. (optimum conditions)

It is known from the literature (Hiatt and Huff, 1975; Meng and Han, 1996) that the dissolution properties of cadmium (Cd) are similar to those of zinc. Moreover, cadmium can be extracted as a separate by-product from pregnant solutions; however, the cadmium content in the sample (i.e., 0.07%) is below the cut-off grade (i.e., 0.2% Cd) (Habashi, 1997), and the form in which cadmium is present could not be determined in this study.

In the experiments conducted under standardized conditions of 120 minutes, 0.15 g/mL solid/liquid ratio, constant stirring speed, and room temperature, the dissolution behavior of cadmium was similar to the dissolution behavior of zinc (Fig. 7). The cadmium dissolution ratios obtained at the optimum 6 M and maximum 12 M NH_3 concentrations were 50.6% and 58.2%, respectively (Fig. 8.). The dissolution ratio of cadmium in the ore sample is lower than that of zinc at all ammonia concentrations which is similar to previous studies (Ehsani, 2020; Ehsani, Ehsani and Obut, 2021).

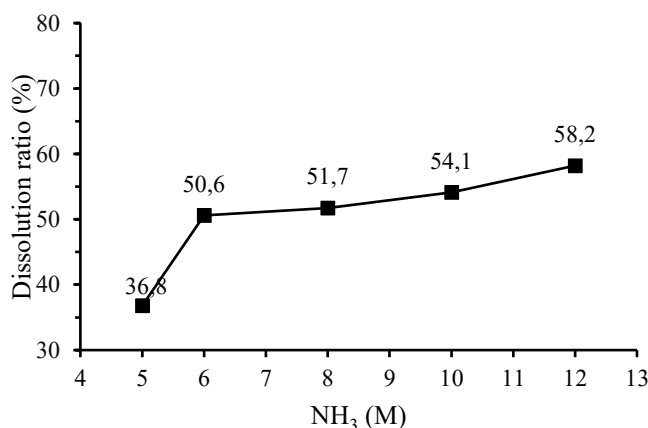


Fig 8. Dissolution behavior of cadmium in the ore sample as a function of NH_3 concentration.

Solid/Liquid (S/L) ratio was studied as a variable parameter in the second series of dissolution experiments. The effects of the solid/liquid ratio (0.05-0.4 g solid/mL solution) on the dissolution rate of zinc and cadmium in the sample were illustrated in Fig. 9. The experiments were carried out at a concentration of 6 M NH_3 , a stirring time of 120 minutes, and a constant solution volume of 400 mL. The dissolution rate decreases with increasing solid/liquid ratio due to the decrease in the ratio of reagent concentration to solid content, which is in agreement with previous similar studies (Ehsani, 2020; Ehsani, Ehsani, and Obut, 2021).

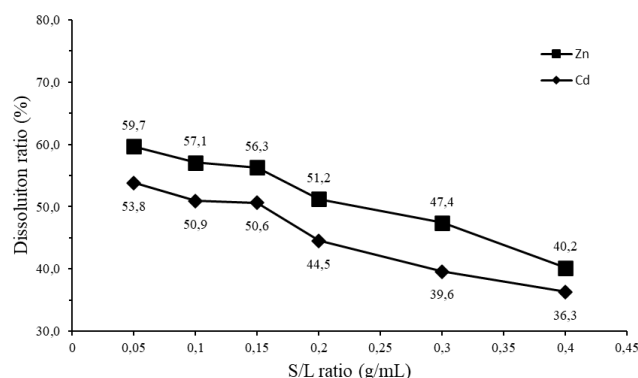


Fig 9. Effect of solid-liquid ratio on zinc and cadmium dissolution rate.

Precipitation (i.e., Drying) Experiments.

The pregnant solutions obtained after dissolution were utilized in the precipitation experiments. The solutions used in the precipitation (drying) processes were obtained by applying the optimum conditions determined for the dissolution process (i.e., 6 M NH_3 , solid/liquid ratio: 0.15 g/mL, 400 mL constant volume, constant stirring speed, room temperature, 120 minutes).

In order to obtain zinc-containing solid compounds from the pregnant solutions, the solution-filled glass/metal containers were placed in a laboratory drying oven at a predetermined temperature (70–210 °C) for precipitation (i.e., drying). Each solution remained at these temperatures for up to 24 hours to ensure complete evaporation and solidification. The resultant dry precipitates were weighed and stored in sealed sample bags for further analysis (XRD, XRF, etc.). Afterward, a selected number of these precipitates were subjected to calcination in a laboratory muffle furnace at a higher temperature (i.e., 400 °C).

The XRD patterns of the solid precipitates obtained as a result of the precipitation process are shown collectively in Fig. 10. Accordingly, zinc-amine carbonate (prominent XRD peaks 2θ (°) = 15.2, 19.9, 22.7) is seen as phases coexisting with hydrozincite in the precipitates obtained through drying at lower temperatures (for instance, 70 °C). Conversely, hydrozincite (2θ (°) = 13.1, 28.2, and 32.8) is the dominant phase formed in precipitates obtained via drying at higher temperatures (e.g., 140 °C and 160 °C), with the zinc-amine carbonate phase absent at these higher temperatures. Notably, contrary to prior studies, only zincite and hydrozincite phases are observed at 190 °C, while partial calcination occurs in the drying process at 210 °C, leading to zincite (ZnO) predominance.

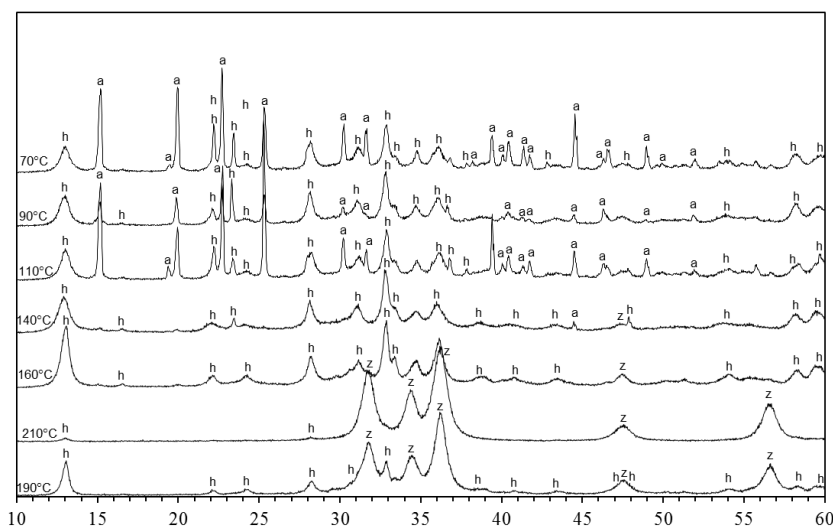


Fig 10. XRD patterns of solids obtained by drying the pregnant solution at different temperatures (a: zinc-amine carbonate, h: hydrozincite, z: zincite)

The zinc solid precipitates obtained in all precipitation experiments up to 190 °C, in accordance with previous studies (Ehsani, 2020; Ehsani, Ehsani, and Obut, 2021), consisted of two distinct zinc-containing solids, zinc amine carbonate ($\text{Zn}(\text{NH}_3)(\text{CO}_3)$ - less amount of that in previous studies) and hydrozincite ($\text{Zn}_5(\text{CO}_3)_2(\text{OH})_6$). As a

significant difference in this study, zinc oxide (ZnO) was formed in the precipitation experiment carried out at 190 °C and 210 °C, indicating that partial calcination took place. This is thought to be due to the different properties of the ore sample or pregnant solution. Alongside this, the significant difference is thought to be more likely due to the disparate drying methods and durations. In this study, long-running (24-hour) drying in a laboratory oven was employed, as opposed to the short-time drying on a hot plate utilized in the aforementioned previous studies.

Important impurities such as dolomite and goethite present in the ore sample are largely insoluble in ammonia solutions. In addition to zinc content, the amount of lead and cadmium impurities in some selected solids (i.e., precipitates) was determined by XRF analysis (Table 2), and it was also shown that other impurities were trace (in the case of Pb) and minor (in the case of Cd) amounts in the solids.

Table 2. Zn, Cd, and Pb contents (%) of some precipitates.

The drying temperature of some solids	Zn (%)	Pb (%)	Cd (%)
70 °C	54.8	0.1	0.26
140 °C	52.9	0.08	0.24
210 °C	69.2	0.07	0.34

Fig. 11 shows the FT-IR spectra of the solid (precipitate) obtained as a result of precipitation by drying at 110°C. The absorptions at wavenumbers of 462, 707, 833, 1044, 1496, and 3273 cm^{-1} in the FT-IR spectrum of this precipitate belong to hydrozincite (Musić et al., 2002; Sanna et al., 2013; Nassar, Moustafa, and Taha, 2016), which was also determined by XRD analysis.

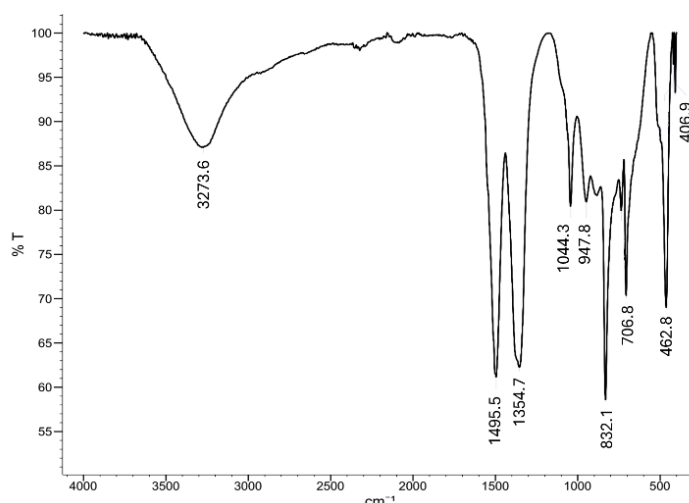


Fig. 11. FT-IR spectrum of the solid obtained after precipitation (Optimum dissolution conditions - Drying temperature 110°C)

SEM-EDS analysis was performed to elucidate the morphological structures of some of these obtained precipitates (Fig. 12-13). While the structure formed from hydrozincite and zinc amine carbonate as a result of drying at low temperatures (e.g., 90 °C) appears more like a leafy structure (Fig. 11), the relatively pure hydrozincite and zincite structures formed by drying at different high temperatures (e.g., 160 and 210 °C) appear as plates and porous (Fig. 13). It is thought that the plate and porous structure formed is the result of the degradation of ammonia and carbonate structures (i.e., zincite formation). Moreover, SEM images of this leafy form (of a highly pure hydrozincite/zinc amine carbonate structure) are in agreement with previous literature studies (Wahab et al., 2008).

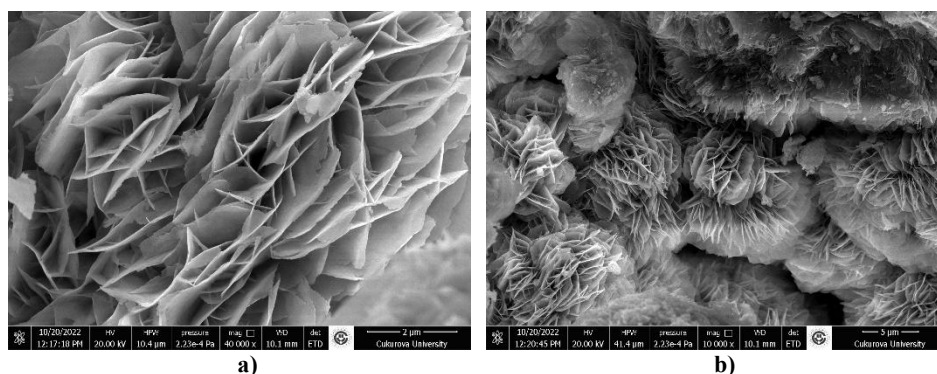


Fig. 12. SEM images of precipitates (magnification: a) $\times 40000$, b) $\times 10000$) at low drying temperature (90 °C)

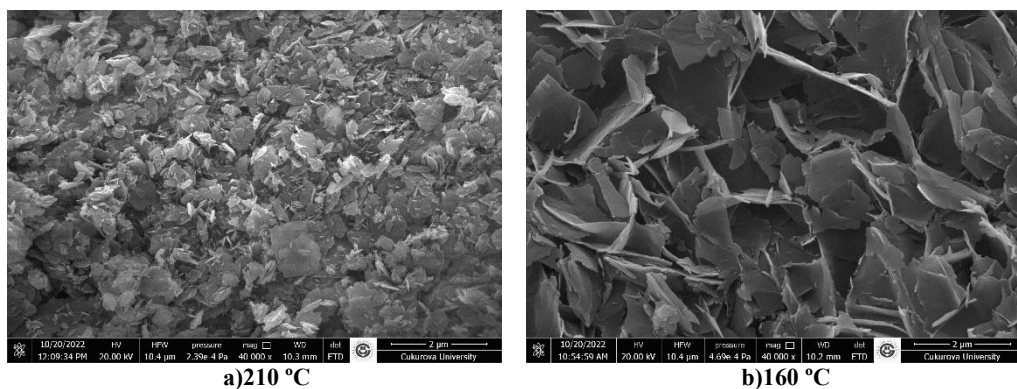


Fig. 13. SEM images of precipitates at high drying temperature (phases present: hydrozincite and a small amount of zinc-amine carbonate (160°C)- hydrozincite and zinc oxide (210°C))

Heat Treatment (Calcination) Experiments.

The precipitates (solids) obtained through drying the pregnant solutions at various temperatures were subjected to heat treatment (calcination) (400 °C-1 hour). The solids resulting from the calcination process were cooled in a moisture-free environment (desiccator) and subjected to XRD and SEM analysis.

XRD analysis of the solids revealed that the hydrozincite and zinc amine phases were completely transformed into the zincite phase (Fig. 14). The XRD patterns of the solids obtained as a result of calcination (400 °C- 1 hour) of the precipitates obtained at different drying temperatures (110 °C and 160 °C). As a result of XRD analysis, it is seen that all solids are transformed into zincite as a single phase.

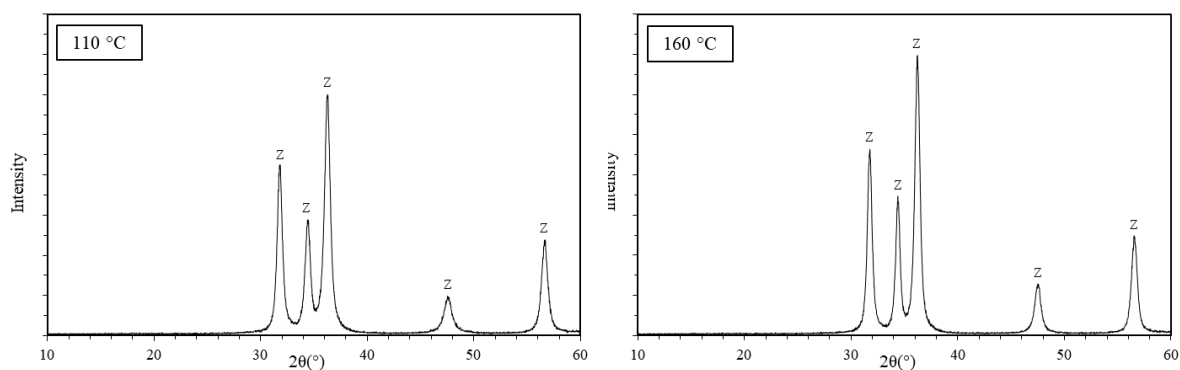


Fig 14. XRD patterns of the solids obtained as a result of calcination (400 °C-1 hour; z: zincite)

Fig. 15 illustrates the FT-IR analysis of the precipitate obtained after drying and the final solid obtained after 400°C heating (calcination). Elevating the temperature to 400°C caused the hydrozincite peaks to disappear completely from the spectrum and the peaks associated with the zinc oxide structure to appear quite prominently. The characteristic peaks of the ZnO structure are observed at approximately 455, 500, 880, and 1394 cm^{-1} (Mayedwa et al., 2017; Noukelag et al., 2020).

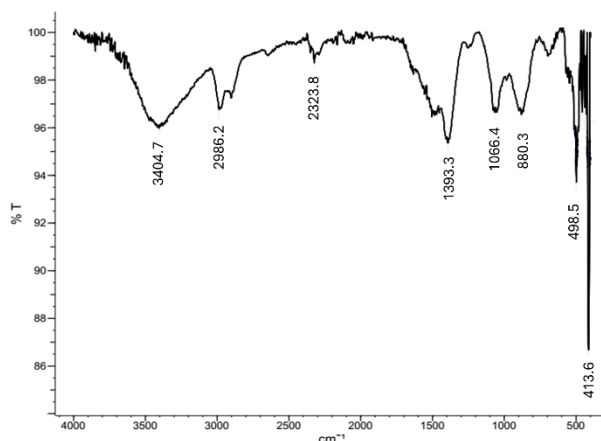


Fig. 15. FT-IR spectrum of the solid obtained after calcination (400°C heating) (Optimum leaching conditions-dominant phase zincite ZnO).

As a result of SEM analysis of the obtained solids, there is a plate and leafy zinc oxide structure (Fig. 16). In terms of crystal structure and chemical content, the EDS analysis result and XRD analysis results (single phase: zinc oxide ZnO) show compatibility.

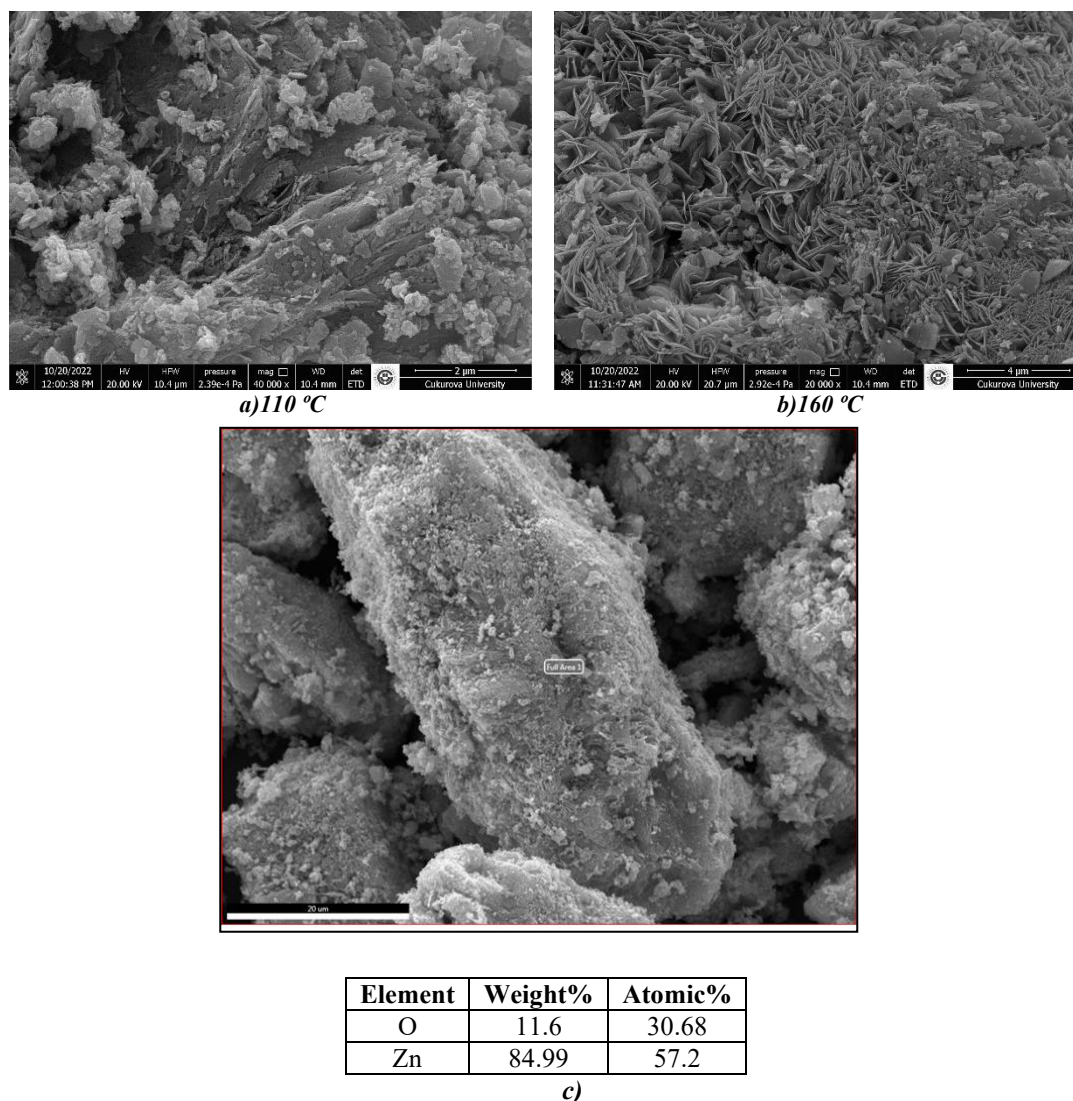


Fig 16. SEM images of the solids were obtained as a result of calcination at a) 110 °C, b) 160 °C, and c) SEM-EDS analysis of the selected area of the calcinated solid.

Conclusions

Considering the results of the experiments and analyses carried out so far, the following conclusions have been reached in general.

- XRD and XRF analyses revealed that the ore sample from the Kayseri region of Türkiye is a non-sulfide zinc ore predominantly containing the smithsonite mineral (ZnCO_3). Significant levels of dolomite and goethite were identified as the main impurities, alongside quartz and clay minerals. Further detailed identification was achieved through XRF, SEM, and ATR-FTIR analyses.
- As a result of the dissolution process, considering the dissolution rate of zinc and cadmium, the optimum conditions were determined as follows: NH_3 concentration 6 M, solid-liquid ratio 0.15 g/mL, stirring speed: constant, stirring time: 120 minutes, and room temperature.
- For future studies, dissolution experiments can be performed at a finer particle size and lower solid/liquid ratio to achieve higher dissolution rates. However, the cost of crushing/grinding, lixiviant, and the energy consumed will, of course, increase.
- Precipitation experiments resulted in the formation of zinc ammine carbonate and hydrozincite as dominant phases using the leaching solution obtained under optimal conditions. Partial calcination during

precipitation at 210°C led to the formation of zincite (ZnO), aligning with findings from limited previous literature studies.

- The SEM images of the precipitates obtained have a leafy-plate structure consistent with previous literature studies.
- XRD and SEM results of the solids obtained post-calcination demonstrated compatibility, confirming the formation of single-phase zincite (ZnO).
- ATR-FTIR analyses of the original ore sample, the solid residue that remained insoluble after leaching under optimum conditions, the solid obtained as precipitate by drying, and the solid obtained from the calcination of this precipitate were performed. As a result of these analyses, the presence of smithsonite as a valuable target mineral, and dolomite and goethite as side-rocks were determined in the ore sample. In addition, the content of the precipitate obtained as a result of drying was found to be predominantly zincite. Consistency between FT-IR and XRD analyses further supported the findings.

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