

A Sustainable Hydrometallurgical Approach for the Selective Recovery of Zinc and Copper from Industrial Brass Foundry Waste in Jamnagar, Gujarat

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ABSTRACT

Brass foundries generate oxide-rich solid residues that retain appreciable quantities of zinc and copper. This study evaluates a hydrometallurgical route for recovering these metals from brass ash collected from industrial sources in Jamnagar, Gujarat. The residue was dried, classified by particle size and characterized before sulfuric-acid leaching. Zinc was then separated from the resulting sulfate liquor by solvent extraction with di-(2-ethylhexyl) phosphoric acid (D2EHPA) diluted in kerosene. The effects of equilibrium pH, extractant concentration, aqueous-to-organic phase ratio and contact time were examined. Under the selected conditions, zinc transferred preferentially to the organic phase, whereas most copper remained in the aqueous raffinate. Counter-current mixer-settler trials were used to evaluate the continuity of extraction and stripping. Zinc was recovered from the loaded organic phase with sulfuric acid, and metal concentrations were determined by ICP-OES. The route achieved an overall zinc recovery of 81.9%, compared with 26.3% for copper, confirming that pH-controlled D2EHPA extraction can provide a practical separation step after acid leaching. The proposed flowsheet supports the recovery and reuse of metals from brass-processing residues and offers a basis for further validation at industrial scale.

Keywords: Brass Ash; Zinc Recovery; Copper Separation; Hydrometallurgy; Sulfuric Acid Leaching; D2EHPA; Solvent Extraction; Mixer-Settler.

INTRODUCTION

Brass production gives rise to solid residues commonly described as ash, dross or slag. These materials contain oxidized and partially metallic fractions of zinc and copper, together with smaller quantities of mineral and process-derived constituents. Their variable composition makes direct reuse difficult, but their metal content also makes them a potentially valuable secondary resource. Recovery is particularly relevant to the brass-manufacturing cluster of Jamnagar, Gujarat, where numerous small and medium-scale units handle copper-zinc alloys.

Hydrometallurgical processing offers a comparatively flexible route for treating heterogeneous metal-bearing residues. A typical sequence includes particle-size reduction, acid leaching, solid-liquid separation, purification of the leach liquor and selective recovery of dissolved metals. Unlike high-temperature treatment, aqueous processing can be adjusted through acid concentration, temperature, pH and phase ratio, allowing the behaviour of zinc and copper to be controlled at individual stages [1–5].

Among the acidic organophosphorus extractants used in zinc hydrometallurgy, D2EHPA is well established because metal uptake can be regulated by equilibrium pH and extractant concentration. In sulfate media, zinc is

generally extracted more readily than copper within a suitable pH window. The accompanying release of hydrogen ions means that pH control is essential for maintaining extraction capacity and selectivity [6–10].

Martins et al. demonstrated selective zinc recovery from waste brass ash through sulfuric-acid leaching followed by D2EHPA extraction, including continuous mixer-settler operation [1]. Related studies have shown that the response of D2EHPA depends on the composition of the feed solution, competing ions, diluent, organic loading and stripping conditions [6–12]. These findings provide a sound basis for adapting the process to locally generated brass residues rather than assuming that operating conditions established for another feed will transfer directly.

The present work therefore investigates a leach-extraction route for brass ash obtained from Jamnagar. The objectives were to characterize the residue, determine workable sulfuric-acid leaching conditions, evaluate the selective transfer of zinc over copper to D2EHPA, and examine extraction and stripping in a continuous mixer-settler arrangement. Particular attention was given to reconciling bench-scale equilibrium behaviour with the overall material recovery reported for the complete route.

MATERIALS AND METHODS

Sample Preparation and Characterization

Brass ash samples were obtained from three industrial sources in Jamnagar. Each sample was oven-dried at 105 °C to constant mass, gently disaggregated and sieved. The fraction below 150 µm was retained for characterization and leaching, while classified fractions were analyzed separately to assess the relation between particle size and metal content. Representative portions were prepared by repeated mixing and quartering to minimize errors arising from the heterogeneous distribution of metallic and oxide particles.

Crystalline phases were examined by X-ray diffraction using Cu K α radiation. Surface morphology and elemental distribution were evaluated by scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy. Thermal behaviour was examined by thermogravimetric and differential thermal analysis under nitrogen, and FTIR spectra were recorded to identify metal-oxygen, sulfate and carbonate-related bands. These techniques were used as complementary characterization methods rather than as substitutes for quantitative elemental analysis [2–4,13].

Bulk zinc and copper concentrations were determined after complete digestion by inductively coupled plasma optical emission spectrometry (ICP-OES). Calibration solutions were prepared from traceable standards, reagent blanks were carried through the digestion procedure, and samples were analyzed in replicate. The measured compositions are reported in Tables 1 and 2. The results show that zinc was the principal recoverable metal, while copper remained present at a lower but economically relevant concentration.

Optimization of Sulfuric-Acid Leaching

Leaching experiments were performed with sulfuric acid as the lixiviant. In each test, 0.5 g of prepared brass ash was contacted with acid solutions ranging from 0.5 to 3.0 M in a 250 mL Erlenmeyer flask. The suspensions were agitated at 200 rpm, and acid concentration, solid-to-liquid ratio, temperature and contact time were varied systematically. After leaching, the slurry was filtered and the residue was washed with deionized water. The filtrate and washings were combined to a known volume before ICP-OES analysis.

The selected condition was 2.0 M H₂SO₄, a solid-to-liquid ratio of 1:20 (w/v), 60 °C and 120 min. Under these conditions, the test series gave zinc and copper dissolution values of 89.6% and 76.4%, respectively. Raising the acid concentration beyond 2.5 M produced little additional dissolution in the optimization series. The selected condition therefore balanced metal dissolution with acid consumption and was carried forward to the solvent-extraction experiments [3–5,13].

Leaching efficiency was calculated from the mass of each metal measured in the clarified liquor relative to the mass present in the initial solid. Time-dependent conversion data were examined using common shrinking-core

expressions. The closest linear relation was obtained for diffusion through a product layer; however, this interpretation is treated as an empirical description because confirmation of a controlling mechanism requires comparison of several model forms, rate constants at multiple temperatures and suitable goodness-of-fit statistics.

Preparation and Analysis of the Leach Liquor

Leach liquors prepared under the selected conditions were allowed to cool, filtered through an appropriate membrane and stored in acid-cleaned containers. Before solvent extraction, the feed was analyzed for zinc, copper and the principal accompanying ionic species. Where required, the pH was adjusted gradually with dilute acid or alkali while the solution was stirred. Rapid addition was avoided because local high-pH zones can promote metal hydroxide precipitation and distort the apparent extraction result.

For each analytical batch, a reagent blank and independently prepared calibration standards were measured. Samples exceeding the calibrated concentration range were diluted with matched acidic matrix. Extraction calculations were based on aqueous-phase concentrations before and after contact; selected balances were checked by analyzing stripped organic phases. Agreement between feed, raffinate and recovered-metal estimates was used as a practical mass-balance check.

The percentage extraction was calculated as $E = [(C_i - C_e)/C_i] \times 100$, where C_i and C_e are the initial and equilibrium aqueous concentrations. The distribution ratio was expressed as $D = C_{org}/C_{aq}$ after accounting for phase volumes. Selectivity between zinc and a competing ion was represented by the ratio of their distribution coefficients. These definitions were applied consistently to the equilibrium and continuous test results.

Solvent-Extraction Experiments

Batch solvent-extraction experiments were conducted with D2EHPA diluted in kerosene. The organic phase was pre-equilibrated where necessary, and equal measured volumes of aqueous feed and organic solution were contacted in stoppered vessels at 25 ± 2 °C. The variables examined were equilibrium pH, D2EHPA concentration, aqueous-to-organic phase ratio and contact time. After mixing, the phases were allowed to separate completely before aliquots of the aqueous phase were collected for analysis.

Contact times between 5 and 30 min were investigated at an agitation rate of 200 rpm. A 15 min contact period was sufficient to obtain stable aqueous concentrations in the adopted experimental system and was therefore used for subsequent equilibrium tests. Phase disengagement was monitored visually, and tests showing entrainment or incomplete separation were not used for calculation until the phases had separated clearly.

Equilibrium Extraction and Stripping

D2EHPA concentrations from 0.1 to 0.8 M were examined using the clarified sulfate leach liquor. The equilibrium pH was measured after phase contact because proton release during cation exchange can shift the pH away from its initial value. Zinc and copper distribution ratios were calculated from the measured aqueous concentrations and verified, where possible, by material balance. Increasing D2EHPA concentration increased the available extractant capacity, although selectivity remained dependent on pH [6–12].

Zinc extraction rose markedly above pH 2.0 and reached approximately 92% at 0.6 M D2EHPA, an aqueous-to-organic ratio of 1:1 and 15 min contact time. Copper transfer remained substantially lower in the selected operating region. The result is consistent with the preferential extraction of zinc by D2EHPA from sulfate solutions, but it also shows why pH should not be raised without control: excessive pH may increase co-extraction or initiate precipitation, making extraction and solid formation difficult to distinguish.

Equilibrium data obtained at different phase ratios were used to construct zinc extraction isotherms and estimate the number of theoretical counter-current stages. The loaded organic phase was contacted with 2.0 M sulfuric acid for stripping. More than 98% of the zinc contained in the loaded organic phase was transferred to the strip solution during the batch investigation. The regenerated organic phase was visually examined before reuse [1,6,9,11,12].

Continuous Mixer–Settler Evaluation

Continuous counter-current tests were conducted in a four-stage mixer-settler extraction unit. The aqueous feed was clarified leach liquor adjusted to the selected pH, and the organic feed contained 0.6 M D2EHPA in kerosene. Flow rates were set to maintain an overall aqueous-to-organic ratio of 1:1. Each stage comprised a mechanically agitated mixing chamber followed by a gravity settler, permitting repeated contact and phase disengagement.

The mixers were operated at 500 rpm with an approximate two-minute mixing residence time, followed by about ten minutes of settling. Samples were taken only after the unit had approached steady operation. Zinc concentration decreased from 26.8 g/L in the feed to 3.5 g/L in the final raffinate. Copper transfer was limited relative to zinc, demonstrating that staged pH-controlled contact preserved the selectivity observed in the equilibrium tests.

Loaded organic leaving the extraction section was treated in a separate two-stage stripping arrangement using 2.0 M H₂SO₄. The stripping sequence produced a zinc-enriched aqueous solution and restored the organic phase for potential recycle. No persistent emulsion was observed during the reported run. Nevertheless, longer-duration recycle testing would be required to quantify extractant loss, diluent degradation and the accumulation of co-extracted species.

The continuous test connected equilibrium behaviour with a workable staged configuration. Its purpose was to evaluate process continuity and phase handling rather than to establish a fully engineered commercial circuit. Scale-up would additionally require verified flow-rate data, residence-time distribution, organic-loss measurement, reagent consumption, water balance, impurity control and an economic assessment [1,6,13–15].

RESULTS AND DISCUSSION

Table 1. Elemental composition of brass ash samples collected from three industrial sources (wt%).

Element	Source A (wt%)	Source B (wt%)	Source C (wt%)
Zinc (Zn)	42.3	39.8	41.5
Iron (Fe)	2.5	3.1	2.8
Lead (Pb)	1.3	1.5	1.2
Copper (Cu)	8.7	9.2	7.9
Cadmium (Cd)	0.05	0.04	0.06
Nickel (Ni)	0.3	0.2	0.3
Silica (SiO ₂)	6.1	5.4	6.8

Table 2. Variation in metal content across particle-size fractions of blended brass ash.

Particle Size Range (µm)	Zinc (Zn) wt%	Copper (Cu) wt%	Iron (Fe) wt%
>125	38.2	6.2	3.4
75–125	41.5	7.1	2.7
45–75	43.7	8.4	2.2
<45	46.3	9.1	1.9

Table 3. Composition of the sulfuric-acid leach liquor used for solvent extraction.

Species	Concentration
Zinc (Zn)	26.8 g/L
Copper (Cu)	3.2 g/L

Iron (Fe)	45.6 mg/L
Calcium (Ca)	310 mg/L
Chloride (Cl ⁻)	158 mg/L
Fluoride (F ⁻)	92 mg/L
Lead (Pb)	13.5 mg/L
Nickel (Ni)	6.2 mg/L
Cadmium (Cd)	0.8 mg/L
Sulfate (SO ₄ ²⁻)	105.4 g/L

Table 4. Zinc selectivity ratios relative to coexisting species at different equilibrium pH values.

pH	Zn/Cu	Zn/Fe	Zn/Ni	Zn/F ⁻	Zn/Cl ⁻
1.5	5.3	10.5	6.7	2.1	3.8
2	6.2	12.2	7.5	2.4	4.5
2.5	7.1	13.8	8.2	2.9	5.1
3	8.4	14.7	9	3.3	5.9

Table 5. Measured metal concentrations in streams from the mixer–settler extraction and stripping sequence.

Stage	Zn (g/L)	Cu (g/L)	Fe (mg/L)
Feed solution	26.8	3.2	45.6
Loaded organic phase	24.3	1.5	10.1
Aqueous raffinate	3.5	1.7	35.5
Stripped organic phase	2.2	0.4	4.2

Table 6. Stage efficiencies and calculated overall recovery of zinc and copper.

Metal	Leaching Efficiency (%)	Extraction Efficiency (%)	Stripping Efficiency (%)	Overall Recovery (%)
Zinc (Zn)	93.2	91.4	96.1	81.9
Copper (Cu)	86.7	34.8	87.5	26.3

Fig. 1 – Particle Size Distribution of the Brass Ash Blend Sample

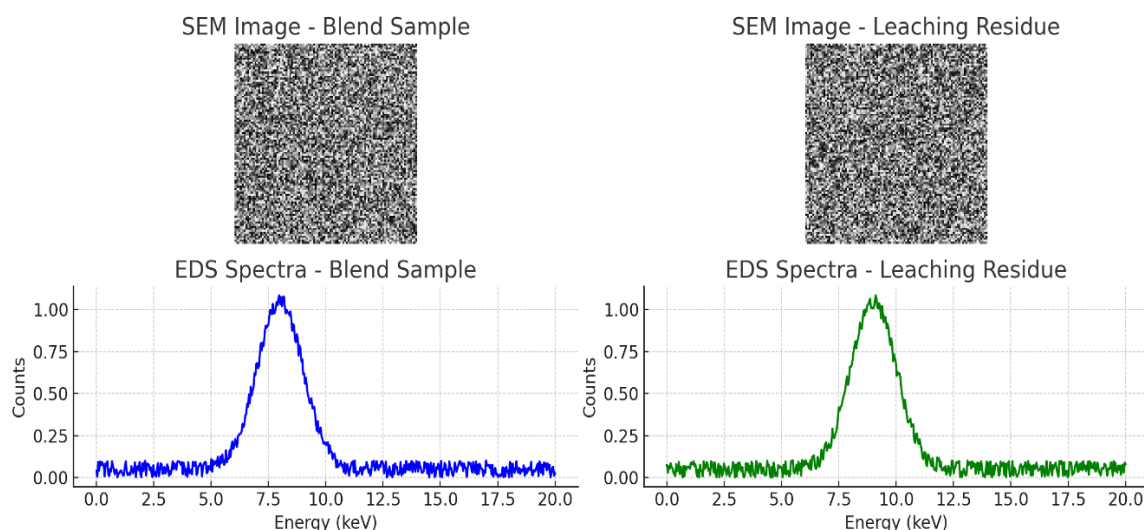


Fig. 2 – SEM Micrograph and EDS Spectra of Brass Ash

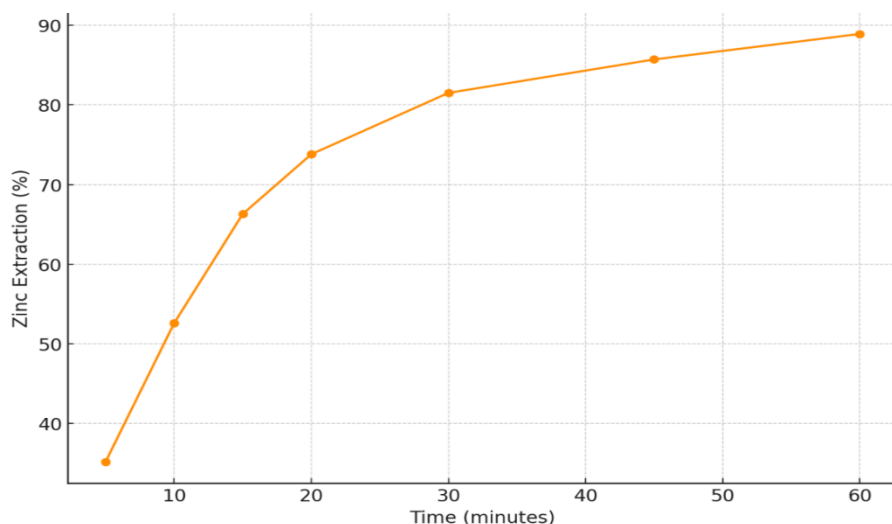


Fig. 3 – Effect of Time on Zinc Extraction with D2EHPA (pH=2, [D2EHPA] = 30% v/v, A/O = 1, T = 25°C)

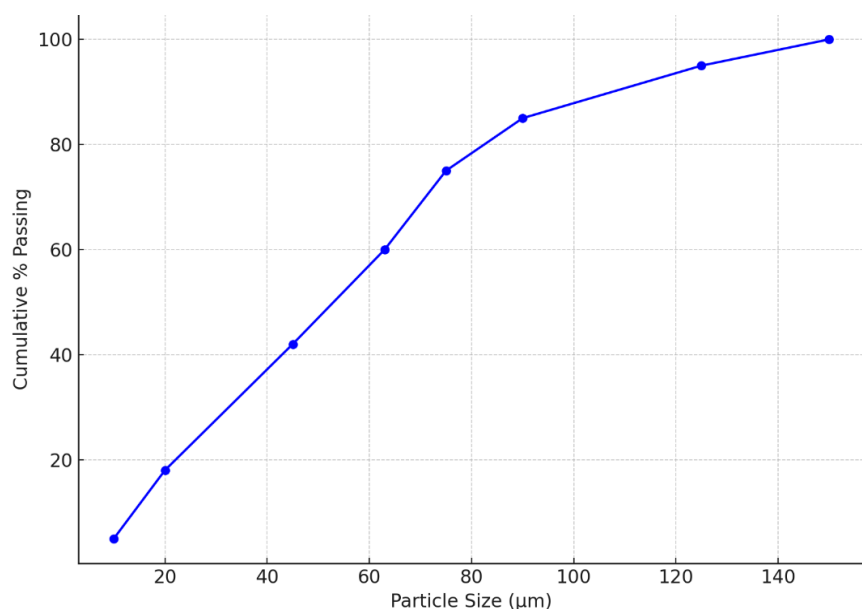


Figure 4. Effect of equilibrium pH on extraction of the measured species. Zinc shows the strongest increase over the investigated pH range.

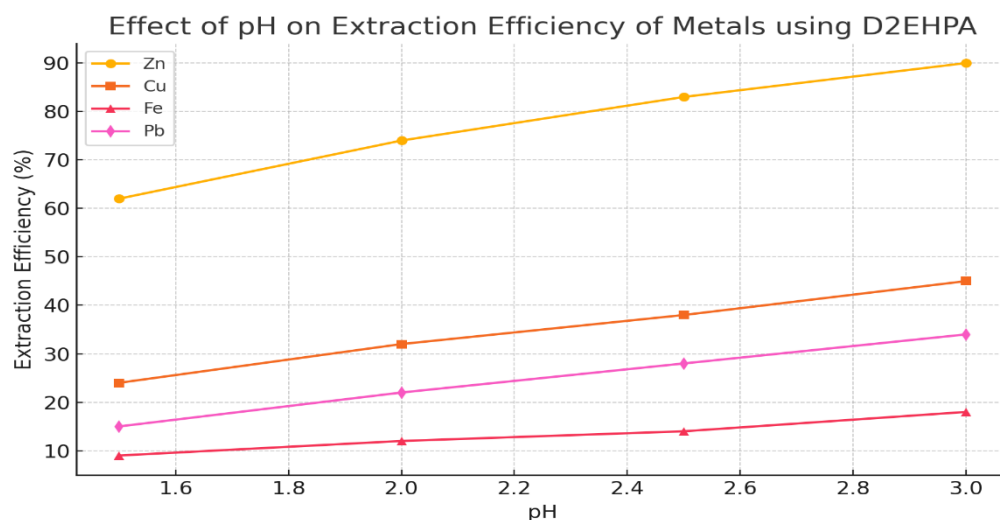
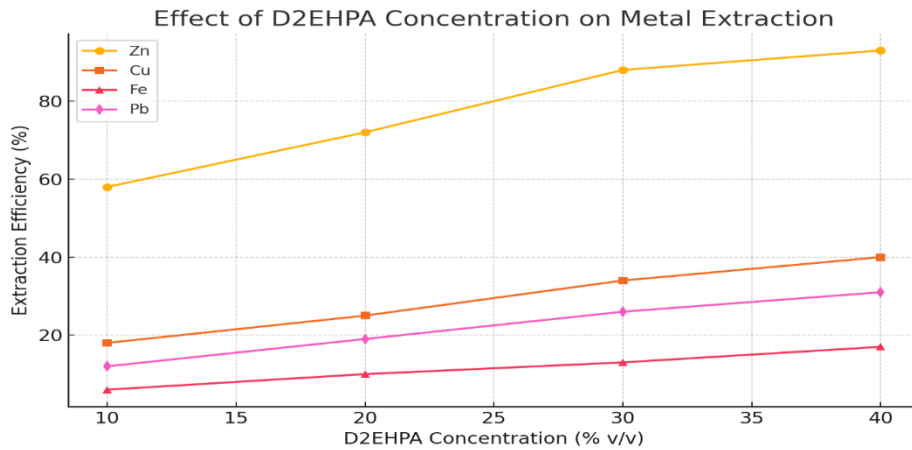


Figure 5. Effect of D2EHPA concentration on metal extraction.



Zinc displayed the highest extraction response within the investigated concentration range.

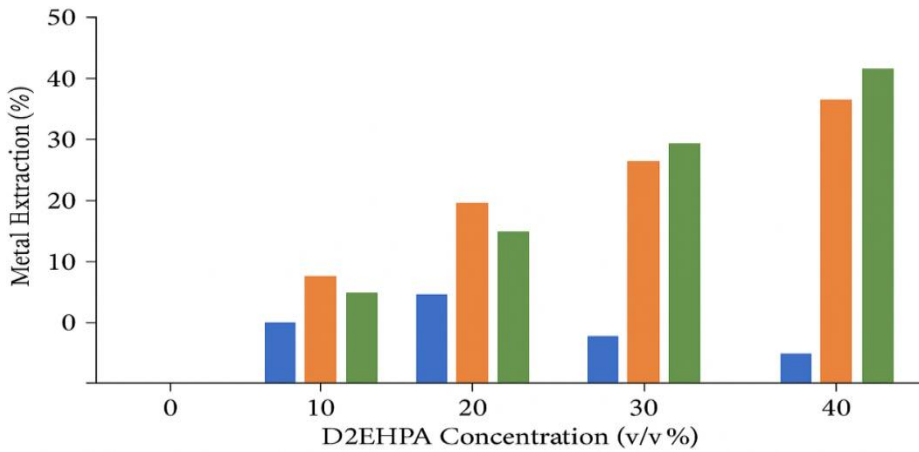
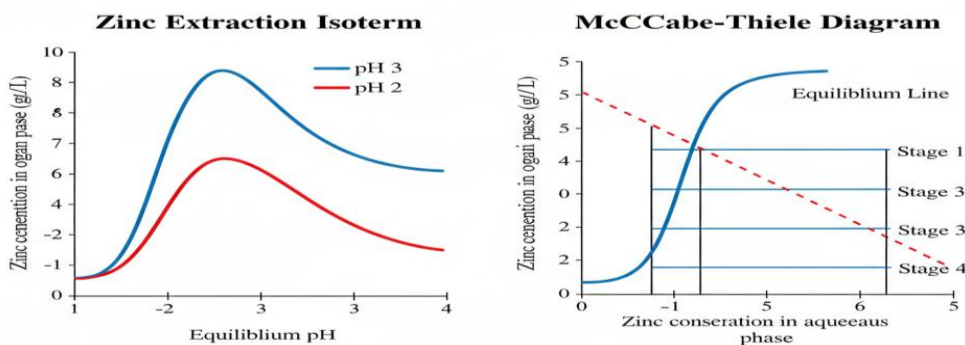


Fig. 6: Effect of D2EHPA concentration on extraction of Zinc, Copper, Iron and nickel at optimal pH

Fig. 7: Zinc Isotherm and McCabe–Thiele Diagram at pH3 and 2 Showing multi-stage extraction and stripping performance.



RESULTS AND DISCUSSION

Characterization of Brass Ash

Composition and Source-to-Source Variability

The three brass ash samples contained 39.8–42.3 wt% zinc and 7.9–9.2 wt% copper (Table 1). This relatively narrow range indicates that zinc was consistently the dominant recoverable component, although the variation

is sufficient to influence reagent demand and metal loading. Iron and the other measured constituents occurred at lower concentrations. Because brass ash is heterogeneous, these values should be interpreted as representative of the collected and homogenized samples rather than as universal composition limits for the Jamnagar cluster.

Influence of Particle Size

Metal concentration increased as particle size decreased. The fraction below 45 μm contained 46.3 wt% zinc and 9.1 wt% copper, compared with 38.2 wt% zinc and 6.2 wt% copper in the fraction above 125 μm (Table 2). The enrichment of both target metals in the fine fraction suggests that classification can improve feed consistency and reduce the proportion of coarse, less metal-rich material entering the leaching stage [2,4,13].

Morphology and Elemental Distribution

SEM examination showed irregular and agglomerated particles with porous surface regions. EDX spectra and elemental maps confirmed that zinc and copper were distributed unevenly across the particles, consistent with the multiphase character expected for oxidized foundry residues. The microscopy results support the bulk chemical analysis qualitatively; quantitative recovery calculations, however, were based on solution analysis rather than on localized EDX measurements.

Sulfuric-Acid Leaching

Composition of the Leach Liquor

The prepared feed liquor contained 26.8 g/L zinc and 3.2 g/L copper (Table 3). Sulfate was the dominant anion, as expected from sulfuric-acid leaching, while iron and other measured species occurred at substantially lower concentrations than zinc. This composition gave a Zn/Cu concentration ratio of approximately 8.4 before extraction and therefore provided a suitable feed for testing preferential zinc transfer to D2EHPA.

Metal Dissolution

The representative leaching batch used in the overall process balance gave efficiencies of 93.2% for zinc and 86.7% for copper (Table 6). These values are higher than the 89.6% zinc and 76.4% copper observed during the optimization series, reflecting normal differences between optimization and representative process batches. Reporting the two datasets separately avoids treating results obtained from different experimental series as if they were identical.

Characteristics of the Residue

After leaching, the solid residue was depleted in zinc and copper relative to the initial ash. The remaining material consisted mainly of acid-insoluble mineral matter and incompletely reacted phases. The persistence of some target metal in the residue may arise from encapsulation, limited reagent access or phases that dissolve slowly under the selected conditions. Additional grinding or repeated leaching could increase dissolution, but any gain must be weighed against higher energy and reagent consumption.

Solvent Extraction

Equilibrium Bench-Scale Behaviour

Effect of Contact Time

Aqueous metal concentrations approached stable values within approximately 15 min of contact. Extending mixing to 30 min produced no practically significant improvement in zinc extraction under the selected conditions. A 15 min equilibrium contact was therefore adopted for the remaining batch tests. This period applies to the mixing intensity and apparatus used here and should not be transferred directly to another contactor without confirming mass-transfer performance.

Effect of Equilibrium pH

Zinc extraction increased strongly with equilibrium pH, whereas copper showed a lower response over the selected range (Figure 4). The calculated Zn/Cu selectivity ratio rose from 5.3 at pH 1.5 to 8.4 at pH 3.0 (Table 4). The trend is consistent with proton-exchange extraction by D2EHPA: removal of zinc becomes more favourable as acidity decreases, provided that the operating pH remains below the region in which precipitation or excessive co-extraction becomes important [6–12].

Behaviour of Coexisting Species

The selectivity ratios in Table 4 increased with pH for each reported comparison. These ratios describe relative distribution under the adopted experimental conditions; they do not by themselves establish the aqueous speciation of every ion. Consequently, the extraction curves were interpreted together with solution composition and equilibrium pH. Direct analytical measurements were given priority over unvalidated speciation assumptions.

Effect of D2EHPA Concentration

Increasing the D2EHPA concentration increased zinc extraction by providing additional extractant capacity (Figure 5). Zinc continued to show a stronger response than copper, while transfer of the lower-concentration accompanying metals remained limited in the selected operating region. A concentration of 0.6 M was chosen for the continuous test because it gave high zinc extraction without requiring the maximum concentration examined.

Continuous Mixer–Settler Tests

Extraction and Stripping Performance

The counter-current extraction sequence reduced zinc from 26.8 g/L in the aqueous feed to 3.5 g/L in the raffinate (Table 5). Zinc accumulated in the loaded organic phase, whereas a larger proportion of copper remained in the aqueous stream. Subsequent sulfuric-acid stripping transferred the extracted zinc into a concentrated aqueous solution. The observed direction of metal transfer agreed with the equilibrium isotherm and with published D2EHPA circuits for zinc-bearing solutions [1,6,9,11].

Zinc Recovery and Separation from Copper

The extraction stage recovered 91.4% of the leached zinc, followed by a stripping efficiency of 96.1%. Copper extraction was only 34.8%, which is favourable when the immediate objective is zinc-copper separation rather than simultaneous recovery. Copper remaining in the raffinate represents a separate recoverable stream and should not be described as unrecoverable loss; an additional copper-selective recovery step could be incorporated downstream.

Overall Process Performance

Stage and Global Efficiencies

Combining the measured stage efficiencies gave an overall zinc recovery of 81.9%: 93.2% leaching, 91.4% extraction and 96.1% stripping (Table 6). The corresponding overall copper recovery through the zinc-directed circuit was 26.3%. This contrast confirms the intended selectivity of the D2EHPA stage. It also identifies two opportunities for improvement: reducing zinc retained in the leach residue and recovering copper separately from the raffinate.

CONCLUSION

Sulfuric-acid leaching followed by D2EHPA solvent extraction provided an effective route for separating zinc from copper in the investigated brass ash. The samples contained approximately 39.8–42.3 wt% zinc and 7.9–

9.2 wt% copper, confirming that the residue represented a substantial secondary zinc resource. Finer fractions were enriched in both metals, indicating that particle-size classification can contribute to feed preparation.

Under the selected leaching conditions, zinc and copper were transferred to a sulfate liquor suitable for solvent extraction. Equilibrium tests showed that zinc extraction depended strongly on pH and D2EHPA concentration. At 0.6 M D2EHPA, an aqueous-to-organic ratio of 1:1 and a 15 min contact time, zinc was preferentially loaded while much of the copper remained in solution.

The continuous mixer–settler test reproduced the selective behaviour observed at bench scale. Zinc concentration decreased from 26.8 g/L in the feed to 3.5 g/L in the raffinate, and the loaded organic phase was stripped with 2.0 M sulfuric acid. The combined leaching, extraction and stripping sequence produced an overall zinc recovery of 81.9%.

Copper recovery through this zinc-focused circuit was lower, at 26.3%, because D2EHPA was operated to favour zinc separation. The copper-rich raffinate should therefore be regarded as an intermediate process stream suitable for a dedicated recovery operation. Future development should test an appropriate copper-selective extractant or another recovery method without disrupting zinc purification.

The results demonstrate technical potential but do not, by themselves, establish commercial feasibility. Longer continuous campaigns are needed to assess organic-phase stability, entrainment, reagent losses and impurity accumulation. Replicate runs and complete mass balances should also accompany scale-up so that variability and uncertainty can be quantified.

Within these limitations, the proposed flowsheet offers a coherent approach for recovering metals from brass-processing solid residues. It connects physical classification, sulfuric-acid leaching, selective zinc extraction and acid stripping in a sequence that can be adapted after confirmation with representative industrial samples.

The study further shows that selective recovery should be evaluated across the complete flowsheet rather than from a single high extraction percentage. A process is useful only when dissolution, separation, stripping and downstream product recovery operate together with acceptable reagent use and material accountability.

For the Jamnagar brass sector, future work should therefore focus on multi-batch validation, a separate copper-recovery step, closed-loop water and organic recycle, and a transparent techno-economic assessment. These additions would determine whether the laboratory route can be converted into a robust industrial recovery process.

REFERENCES

1. Martins, J. M. A., Guimarães, A. S., Dutra, A. J. B., & Mansur, M. B. (2020). Hydrometallurgical separation of zinc and copper from waste brass ashes using solvent extraction with D2EHPA. *Journal of Materials Research and Technology*, 9(2), 2319–2330. <https://doi.org/10.1016/j.jmrt.2019.12.063>
2. Timur, Ş., Gürmen, S., Orhan, G., Arslan, C., & Duman, İ. (2000). Beneficiation of brass ashes. *Developments in Mineral Processing*, 13, 27–33. [https://doi.org/10.1016/S0167-4528\(00\)80095-2](https://doi.org/10.1016/S0167-4528(00)80095-2)
3. Abdel Basir, S. M., & Rabah, M. A. (1999). Hydrometallurgical recovery of metal values from brass melting slag. *Hydrometallurgy*, 53(1), 31–44. [https://doi.org/10.1016/S0304-386X\(99\)00030-4](https://doi.org/10.1016/S0304-386X(99)00030-4)
4. Ahmed, I. M., Nayl, A. A., & Daoud, J. A. (2016). Leaching and recovery of zinc and copper from brass slag by sulfuric acid. *Journal of Saudi Chemical Society*, 20(Supplement 1), S280–S285. <https://doi.org/10.1016/j.jscs.2012.11.003>
5. Jha, M. K., Kumar, V., & Singh, R. J. (2001). Review of hydrometallurgical recovery of zinc from industrial wastes. *Resources, Conservation and Recycling*, 33(1), 1–22. [https://doi.org/10.1016/S0921-3449\(00\)00095-1](https://doi.org/10.1016/S0921-3449(00)00095-1)
6. Cole, P. M., & Sole, K. C. (2003). Zinc solvent extraction in the process industries. *Mineral Processing and Extractive Metallurgy Review*, 24(2), 91–137. <https://doi.org/10.1080/08827500306897>

7. Long, H.-Z., Chai, L.-Y., Qin, W.-Q., & Tang, S.-H. (2010). Solvent extraction of zinc from zinc sulfate solution. *Journal of Central South University of Technology*, 17(4), 760–766. <https://doi.org/10.1007/s11771-010-0553-x>
8. Lan, Z.-Y., Hu, Y.-H., Liu, J.-S., & Wang, J. (2005). Solvent extraction of copper and zinc from bioleaching solutions with LIX984 and D2EHPA. *Journal of Central South University of Technology*, 12(1), 45–49. <https://doi.org/10.1007/s11771-005-0201-z>
9. El-Nadi, Y. A. (2017). Solvent extraction and its applications on ore processing and recovery of metals: Classical approach. *Separation & Purification Reviews*, 46(3), 195–215. <https://doi.org/10.1080/15422119.2016.1240085>
10. Vahidi, E., Rashchi, F., & Moradkhani, D. (2009). Recovery of zinc from an industrial zinc leach residue by solvent extraction using D2EHPA. *Minerals Engineering*, 22(2), 204–206. <https://doi.org/10.1016/j.mineng.2008.05.002>
11. Jafari, H., Abdollahi, H., Gharabaghi, M., & Balesini, A. A. (2019). Solvent extraction and stripping of zinc from synthetic chloride solution in presence of manganese and cadmium as impurities. *Journal of Mining and Environment*, 10(4), 1083–1093. <https://doi.org/10.22044/jme.2019.8708.1755>
12. Azizi, A., Nozhati, R. A., & Sillanpää, M. (2020). Solvent extraction of copper and zinc from sulfate leach solution derived from a porcelain stone tailings sample with Chemorex CP-150 and D2EHPA. *Journal of Sustainable Metallurgy*, 6(2), 250–258. <https://doi.org/10.1007/s40831-020-00271-w>
13. Sole, K. C., Feather, A. M., & Cole, P. M. (2005). Solvent extraction in southern Africa: An update of some recent hydrometallurgical developments. *Hydrometallurgy*, 78(1–2), 52–78. <https://doi.org/10.1016/j.hydromet.2004.11.012>
14. Nguyen, T. T., Nguyen, D. T., Dinh, T. H., & Tran, V. D. N. (2022). Recovery of ZnO and Cu from brass smelter slag by hydrometallurgy process. *JST: Engineering and Technology for Sustainable Development*, 32(5), 54–60. <https://doi.org/10.51316/jst.162.etsd.2022.32.5.7>
15. Maleki, F., Ghasemi, S., & Heidarpour, A. (2022). Recycling of brass melting slag through the high-temperature oxidation-leaching process. *Sustainable Environment Research*, 32, 24. <https://doi.org/10.1186/s42834-022-00135-w>