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A Qualitative Analysis of the Recycling Procedures for Lithium-ion Batteries

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Abstract

Due to the widespread use of e-mobility, a lot of lithium ion batteries (LIB) end up in the landfill. Strategies for recycling and disposal must be developed and implemented immediately. End of Life (EoL) LIBs urgently require environmentally friendly, safe, and cost-effective disposal options. This study evaluated the recycling and reclamation procedures of 44 commercial recyclers. The "Strategic Materials Weighting And Value Evaluation" (SWAVE) qualitative assessment matrix is proposed and used to compare the strategic importance and value of various EoL LIB materials. By comparing the final form or composition of recycled material following the recycling processes, industrial processes, and industry type (primary sector, manufacturer, or recycler), sustainability and quality are evaluated. SWAVE is applied to each organization, delivering a score out of 20, with a bigger number showing that more materials can be reused. Six well-known recycling companies' separation procedures and resources are further discussed. The majority of recyclers focus on high-value metal extraction rather than closed-loop recycling of the metals or component materials, highlighting an environmental and technological gap. These recyclers use one or more mechanical treatments, pyrometallurgy, or hydrometallurgy. Reuse and repurposing of materials (closed-loop recycling) should be considered for further development rather than merely recycling or recovering metals in order to enhance the current circular economy of batteries. It is necessary to conduct additional research on the environmental consequences of recycling or recovering one material over another.

Keywords: Jarosite buildups; Separation; Recovery; Adsorption of heavy metal ions; Purification

Introduction

Jarosite deposits (JR) delivered during sulfuric corrosive draining of the concentrate of the wet zinc refining process are strong waste. It is described by fine granularity, high water, major areas of strength for content, high satisfied of weighty metal particles, and unfortunate steadiness, in this way is delegated a dangerous modern strong waste. Due to the presence of toxic elements like lead, zinc, and sulfur as well as heavy metals and other contaminants, JR is typically stored at tailing dams. In China, jarosite deposits are for the most part amassed nearby and the yearly collection of JR has surpassed 1 million tones. It has been an urgent task to figure out how to treat, use, and make this JR harmless.

The majority of research up to this point has primarily focused on the recovery of contained metals like Cd, Zn, Ag, Cu, and Pb and its use in concrete. I investigated the possibility of partially replacing fine aggregate with JR. The favorable nonleaching results of heavy metals and the good strength of fly ash-filled JR-filled concrete demonstrated that JR could be utilized for construction purposes [1]. However, valuable metals will not be utilized as a result of this approach. Zn, Pb, Cu, Cd, and Ag were recovered from JR through alkali leaching and roasting in NH4Cl. Zn, Pb, Cu, Cd, and Ag were extracted to greater than 95%, and the roasting process released 55 percent by weight of Fe and SO2 into the air in the final residue. While the recovery of iron has been neglected, the roast-leach method is an efficient method for recovering valuable metals from JR.

Extensive examination have likewise been led to recuperate iron from strong squanders by direct decrease followed by attractive division. Through direct reduction, the lead and zinc compounds in the JR are reduced to the metallic lead and zinc, which volatilize into the smoke and can be recovered from the off gases. JR is reduced by a carbon source at elevated temperatures, where the addition of CaO would capture any generated CaS. The iron and sulfur in JR are reduced to metallic iron and CaS, which are found in the non-magnetic tails

(NMT) and can be recovered through grinding-magnetic separation of the reduction product.

On the other hand, a significant amount of acidic wastewater will be discharged during the wet zinc smelting process. This wastewater by and large has an extremely low pH and contains high centralizations of weighty metal particles, like Cu, Pb, As, Co, and so on. If this kind of wastewater is not treated before being released into the environment, it will seriously harm humans and the ecosystem [2]. Adsorption, solvent extraction, reverse osmosis, and other membrane approaches are just a few of the chemical approaches that have been investigated for the purpose of eliminating these harmful metal ions. Among them, dissolvable extraction is a moderately basic strategy, yet unambiguous and costly solvents are expected to remove every contamination. When CaS provides excess S2 ions and the heavy metal ions precipitate as their sulfides, the non-magnetic tails (NMT) from the direct reduction-magnetic separation process can be used to remove the heavy metal ions at a relatively low cost.

Experimental

Materials

This study's JR sample was obtained on-site from Hanzhong Zinc Industry Co., Ltd. in China's Shaanxi Province. Table 1 displays its

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chemical composition. Chemical titration was used to measure the iron element, and the ICP-MS method (PlasmaMS 300) was used to analyze the other elements. Ammoniojarosite (NH4Fe3(SO4)2(OH)6), plumbojarosite (Pb(Fe3(SO4)2(OH)6)2, and franklinite (ZnFe2O4) were the primary crystalline phases that were present in the JR sample, according to the X-ray powder diffraction (XRD) analysis of the JR sample performed with Cu-K radiation at a scanning rate of 10°/min from 10° to 90 As a reducing agent, Hanzhong Zinc Industry Co., Ltd.'s bituminous coal sample from Shaanxi Province was used [3]. It has 4.56 percent moisture, 17.36 percent ash, 28.88 percent volatiles, and 49.20 percent fixed carbon. To fix sulfur in the decrease item as opposed to volatilize very high, CaO of scientific grade was added.

This study also obtained the wastewater sample from Hanzhong Zinc Industry Co., Ltd. in China's Shanxi province. The wastewater has a pH of 2. Investigation results show that the grouping of Compact disc, As, and Pb particles are 457.55 mg/L, 1.6 mg/L, and 5.95 mg/L, separately. The UV-5500 PC UV/Vis Spectrophotometer was used to measure the solution's Cd, pb, and As ion concentrations, while the ICP-MS method (PlasmaMS 300) was used to measure the solution's As ion concentration [4]. The UV/Vis Spectrophotometer uses the following method of detection: creating a standard curve that shows the ion concentration and absorbance, and then determining the ion concentration using the sample's absorbance. Thermo spectrometer (Al K X-ray source) was used for X-ray photoelectron spectroscopy (XPS) analysis.

Experimental methods

There were two parts to the experimental study: the use of the NMT to remove cadmium, arsenic, and lead ions from acidic wastewater after direct reduction roasting and magnetic separation. A simplified representation of the experimental procedure.

Zinc hydrometallurgy's JR is first combined with reducing coal and CaO to form pellets, which are then directly reduced by roasting. Lead and zinc are extracted from the dust through volatilization. Through grinding and magnetic separation, metal iron can be recovered from the reduction roasting slag. Second, the zinc hydrometallurgy's acid wastewater is treated with the non-magnetic tails [5]. This process is novel because it uses NMT to treat zinc hydrometallurgy wastewater in addition to treating hazardous waste JR and recovering valuable metals from JR.

Direct decrease simmering followed by attractive detachment

JR, CaO, bituminous coal, and water were combined as one as per the weight proportion of 100:27.5:25:35 and afterward were squeezed into pellets [6]. The pellets were roasted in an atmosphere furnace after being placed in ceramic crucibles. Coal is utilized as a decreasing specialist, to guarantee a lessening air, nitrogen has been controlled to go through the environment heater at a consistent speed during the whole broiling process. The temperature ranged from 1273 K (1000 °C) to 1573 K (1300 °C), and the roasting time ranged from 20 to 150

minutes. The reduction product was then brought down to room temperature. Chemical titration was used to measure the iron element, chemical titration was used to measure the lead, zinc, sulfur, total iron, and metalized iron content of the reduction product, and the ICP-MS method was used to analyze the other elements.

The reduction product was wet ground to a depth of 25 millimeters and crushed to a size of 2 mm. At a magnetic field intensity of 48 kA/m, a low-intensity magnetic separator model XCGS-73 was used to recover metallic iron from the reduction product [7]. The chemical and ICP-MS methods were used to analyze the magnetic concentrate's total iron content.

Mechanisms of reactions

Coal was a reducing agent during the direct reduction process. Lead and zinc were recuperated by volatilization, and iron was changed over into metallic iron and recuperated by crushing and attractive partition. The stoichiometric proportion for carbon for franklinite direct decrease is 2:1, and the stoichiometric proportion for carbon for JR direct decrease is 6.25:1 [8]. Metal sulfides were used to get rid of the wastewater's heavy metal ions [7]. Using a Carl Zeiss EVO18 scanning electron microscope (SEM) equipped with an energy dispersive spectrum (EDS), the microstructures of the reaction products were examined.

Discussion

During the direct reduction process, the transformation of lead, zinc, and iron minerals into their metals is influenced in significant ways by the dosage of coal, the reduction roasting temperature, and the reduction roasting time.

We looked into how coal dosages affected the direct reduction of JR. The cooking temperature and time length were kept steady at 1473 K (1200 °C) and 120 min individually [9]. The results show that the lead and zinc volatilization rates, which were consistently greater than 95% and 99%, had almost no effect on the coal dosage, which ranged from 20% to 30%. However, the metallization rate of iron increased rapidly from 59.97% to 83.82% when the dosage of coal was increased from 20.0wt% to 25.0wt%. The iron metallization rate does not significantly change when the dosage of coal is greater than 25%. The fact that the sulfur volatilization rate gradually decreases with increasing coal dosage indicates that improving the reducing atmosphere is beneficial for lowering the sulfur volatilization rate [10]. Additionally, when the coal dosage is greater than 25%, there is no significant change in the sulfur recovery rate. As a result, the coal dosage of 25% was chosen as the best setting for future experiments.

To explore the impact of decreased temperature on JR direct decrease, cluster tests were led at the decreased temperatures going from 1273 K (1000 °C) to 1572 K (1300 °C). Different boundaries were kept reliable, or at least, coal dose of 25wt% and decrease season of 120 min. As depicted the decrease in temperature impacted the lead, zinc volatilization rate, and iron metallization rate. The lead volatilization rate increased from 62.62% to 95.77% and the zinc volatilization rate increased from 85.59% to 99.85% when the reduction temperature increased from 1273 K (1000 °C) to 1423 K (1150 °C) [11]. In addition, the volatilization rate did not change significantly when the reduction temperature was raised. From 1273 K (1000 °C) to 1523 K (1250 °C), the rate of iron metallization increased nearly linearly with temperature. At 1523 K (1250 °C), the rate of iron metallization reached 91.63%. The decreased temperature affected the volatilization of sulfur, which stayed beneath 3% throughout the whole tried temperature range from 1273 K (1000 °C) to 1572 K (1300 °C). Taking into account these outcomes, the ideal decrease temperature of 1523 K (1250 °C) was chosen.

To evaluate their effects on JR direct reduction, the reduction times (i.e., 30, 60, 90, 120, and 150 min) were chosen while maintaining a coal dosage of 25% and a reduction temperature of 1523 K (1250 °C). As depicted in Fig. 3(c): Between 30 and 150 minutes, the reduction time had little effect on the lead and zinc volatilization rates, which were respectively greater than 96% and 99% [12]. At longer reducing times, the iron metallization rate remained constant and increased from

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approximately 89.71 percent at 30 minutes to over 91.97 percent at 60 minutes. Sulfur's volatilization rate decreased slightly as the reduction time increased, but remained below 3% for all tests conducted between 30 and 150 minutes. 60 minutes was determined to be the best reduction time [13-19].

In light of the outcomes introduced over, the ideal circumstances for the JR direct decrease were chosen as follows: coal dosage of 25%, a 60-minute reduction time, and a reduction temperature of 1523 K (1250 °C).

Conclusion

Surfactant adsorption has been studied in systems containing various particle types (silica, kaolinite, and their mixtures). As per the outcomes got for 2.5% silica particles in 80 mM $CuSO_4$ and pH 2 suspensions, the surfactant expansion hardly adjusts the powerful versatility and zeta potential. However, the higher the surfactant concentration, the more pronounced the flocculating effect is, as measured by particle size and sedimentation rate. Under operating conditions, the flocculating effect caused by low surfactant concentrations is the cause of this phenomenon.

The powerful versatility of kaolinite suspensions has been examined in similar circumstances, and for this situation, a change was created in the extremity of the molecule charge when CTAB fixation is expanded. Even more, as the electrokinetic charge density changes, the mobility rises in accordance with Maxwell-Wagner-O'Konski relaxation, and the inertial relaxation suggests an increase in particle size at the highest CTAB concentration. This result is consistent with the increase in sedimentation rate and the average particle size measurements.

Finally, surfactant addition has been used to investigate how mixtures of silica and kaolinite behave. The distinctions at high recurrence between model expectations (determined as the weighted normal of the two sorts of particles) and trial results show that accumulation among kaolinite and silica particles is occurring. This end is determined by size appropriation spectra and sedimentation rate. SEM images also show how the aggregates change over time, becoming increasingly complex structures as CTAB is added.

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Conflict of Interest

None

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