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# REVIEW OF THE GALVANIC STRIPPING PROCESS FOR USE IN TREATING OXIDIZED METAL WASTES

*C.-M. Chang, H. Gu, and T.J. O'Keefe, Department of Metallurgical Engineering and Materials Research Center, University of Missouri-Rolla, Rolla, MO, 65401*

**ABSTRACT** A new process which is applicable for the treatment of waste residues associated with the metals industry is currently being developed. The unique part of the technology is the use of solid metal reductants in organic solvent systems to spontaneously remove contained impurity ions. The engineering options, termed simultaneous or separate stripping, that can be used in a flow sheet design using the galvanic stripping process are described. In addition, the effects of various operating parameters on the efficiency of the process are described. Examples of the variables which influence the process kinetics include the type of metal or alloy used, the impurity ion concentration, the chemical concentrations of the active organic and aqueous solutions and their oxygen contents. Tentative flow sheets of how the process could be used in the treatment of iron-zinc neutral leach residue from an industrial operation are discussed.

**KEYWORDS:** solvent extraction, metallurgy, oxidized waste, iron, zinc

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## INTRODUCTION

The oxidized metal wastes bearing zinc and iron are mainly associated with the carbon steelmaking dusts and leaching residues of zinc plants. The majority of these wastes have been classified as hazardous because of contained impurities such as lead, cadmium, and chromium which cause the material to fail the EPA leachability standard tests for disposal. The pretreatment of the wastes required for landfilling are a very expensive and technically questionable option.

The electric arc furnace (EAF) shops presently account for nearly 30 percent of domestic steel output and are projected to grow to 50 percent by the year 2000. As a hazardous waste [1], EAF dusts contain around 20% zinc, the only potential for substantial by-product revenue to offset waste processing costs. A summary of the potential quantities of EAF dust and zinc, lead, and cadmium contained in EAF dust for these years is presented in Table 1 [2].

About 60 percent of the steel is produced by the blast furnace (BF) and basic oxygen furnace (BOF) with dust around 4-10 kg/t for BF and 10-20 kg/t for BOF. The zinc content (less than 10%) of BF/BOF dusts is low compared with EAF dust and it is generally not economical to treat the residue to recover zinc. But, reprocessing of these dusts as environmentally-forced recycling has been given more attention in the last few years due to the potential landfill liability and the increasing cost of disposal by dumping.

Over 80% of the world's zinc supply currently originates from the roast-leach-electrolysis process. Zinc sulfide concentrates are roasted in air to produce a calcine which consists mostly of zinc oxide (ZnO) but also some zinc ferrite (ZnO•Fe<sub>2</sub>O<sub>3</sub>). Zinc oxide is readily soluble using a neutral leach (4.0 pH) stage with dilute sulphuric acid. An additional hot acid leaching stage is necessary to dissolve zinc ferrite if high zinc recovery (over 95%) is desired. Dissolved iron is difficult to

precipitate from acid solution, but three technologies have been used: jarosite, goethite, and hematite. Unfortunately, some impurity metals (Zn, Pb, Ni, Cd, Cu, As, etc.) are present with the iron precipitates, and these residues may no longer be acceptable. Some general information on the iron precipitation technologies are illustrated in Table 2 [3, 4].

It was estimated that the western world's consumption of zinc metal in the 1990's would be about 5,800,000 metric tons [5]. The disposal of huge volumes of hazardous waste for both neutral leach residues and iron precipitates represents a serious environmental problem which is generating social and economical difficulties for the mineral and metal industry.

### ***Processes for treatment of zinc- and iron-bearing oxide wastes***

The recovery of valuable metals and insuring compliance with environmental regulations are necessary in the development of any new processes for treating the wastes. The processes can basically be categorized as

pyrometallurgical, hydrometallurgical, or their combinations.

Pyrometallurgical treatments involve thermal reduction/volatilization of zinc, lead, and cadmium as concentrated oxides or impure metals, and the iron recovered as a non-hazardous and disposable slag. The Waelz kiln process has been commercially used for many years to recover zinc from various residues such as EAF dusts. In the process, the unagglomerated dust and coke are fed into a gas-fired rotary kiln. After reduction of the zinc and lead oxides, the vapors are reoxidized in the gas phase, carried out of the kiln, and captured in a baghouse as a crude oxide [6, 7]. Similar thermal treatment processes have been introduced as converter smelting (Sirosmelt), half shaft furnace (Preussag Miike-Mitsui), and electrothermic zinc process (Ryoho-Onahama) [8-10]. The main competitions for the Waelz process are the plasma smelting process, electric furnace process (Elkem), flame cyclone process (St. Joe/HRD), and Inmetco direct reduction process [8, 11-14]. The Inmetco process has the advantage of

**TABLE 1. POTENTIAL FOR CONTAINED METALS IN EAF DUST (IN SHORT TONS).**

|         | Year—1995 | Year—2000 |
|---------|-----------|-----------|
| Dust    | 750,000   | 1,000,000 |
| Zinc    | 136,000   | 182,000   |
| Lead    | 17,200    | 23,000    |
| Cadmium | 374       | 500       |

\*Assumed EAF dust average composition: 18.1% Zn, 2.3% Pb, 0.05% Cd.

**TABLE 2. IRON PRECIPITATION TECHNOLOGIES IN ZINC LEACH.**

| Process  | Precipitated mineral            | Residue |        | Composition of residue (%) |       |       | Leaching parameter |                 |     |
|----------|---------------------------------|---------|--------|----------------------------|-------|-------|--------------------|-----------------|-----|
|          |                                 | t/t ore | volume | Fe                         | Zn    | S     | T (°C)             | $P_{O_2}$ (MPa) | pH  |
| Jarosite | $MFe_3(SO_4)_2(OH)_6$           | 0.40    | High   | 25-30                      | 4-6   | 10-12 | 95                 | -               | 1.5 |
| Goethite | -FeOOH                          | 0.25    | Medium | 40-45                      | 5-10  | 2.5-5 | 90                 | -               | 3.0 |
| Hematite | -Fe <sub>2</sub> O <sub>3</sub> | 0.18    | Low    | 50-60                      | 0.5-1 | 2-3   | 200                | 2               | -   |

converting the iron content to dry-reduced iron ore which has a good value. All other processes produce non-hazardous disposable slags and impure metal phases. Capital cost will probably be the critical factor in process selection. Many of the existing pyrometallurgical treatments produce a concentrated zinc oxide fume which is potentially treatable using conventional hydrometallurgical techniques

Hydrometallurgical processes involve the direct dissolution of the waste, solution purification, and precipitation or electrowinning to recover zinc values and ensure the non-hazardous disposable residues. Systems of leaching include sulfate, chloride, ammoniacal, alkaline (zincate), aqueous chlorine, and cyanide [14]. The sulfate system is most commonly used when electrolytic recovery of zinc is desired.

Generally, the treatment of EAF dusts can be conducted by the thermal process to generate non-hazardous iron slag and zinc-lead-bearing oxide fumes that continue with hydrometallurgical extraction for metal values. The zinc neutral leach residues and jarosite/goethite precipitates can be treated by both pyrometallurgical and hydrometallurgical processes [14] but are questionable economically. For BF/BOF dusts with low zinc content, the possible treatment method is internally recycling by a sinter plant, such as Inmetco process. In this process, iron oxide is reduced to form foundry pig iron as well as environmentally stable slags, and non-ferrous zinc, lead, and cadmium, are volatilized and re-oxidized in the furnace atmosphere until the same composition as EAF dust. Then, the upgraded dusts can be treated as EAF dusts [15]. Regardless of the type of waste or process chosen, it is obvious that technical activity in this challenging area will continue to expand in the future.

### ***Iron removal by solvent extraction in hydrometallurgical processes***

In the treatment of zinc-iron-bearing oxide waste by hydrometallurgical processes, a strong sulfuric acid leach is necessary for high zinc recovery because of the presence of zinc ferrite. As the zinc dissolves, iron is simultaneously soluble in the leachate which is difficult to separate and eliminate from the solution. Traditional methods of iron removal have included precipitation as jarosite, goethite, and hematite, and cementation using zinc metal. A hot pressure leach is usually required in the iron precipitation process. Both processes are related to an electrochemical redox reaction, and they generate solid residues with virtually no commercial value that are sufficiently contaminated to present an environmental problem.

The solvent extraction of ferric iron from acid zinc sulfate solution originating from strong acid leaching of neutral leach residue offers an alternative to the conventional precipitation method [16]. Iron impurities in the acidic solution are removed by the selective extraction of  $\text{Fe}^{+3}$  using a suitable organic solvent. The aqueous solution is then separated from the organic and treated by a conventional solution purification procedure prior to electrowinning. The extracted  $\text{Fe}^{+3}$  is stripped from the organic as a commercial product for water treatment or iron oxide pigment.

Although research has shown the extraction of iron as  $\text{Fe}^{+3}$  into solvent such as di-(2-ethylhexyl) phosphoric acid (D2EHPA) to be viable, stripping of the iron from loaded solvent proved troublesome. A very low pH acid solution, such as 6N HCl [16], is usually required to strip iron from the solvent to give a low concentration of  $\text{Fe}^{+3}$ . Economical and easy stripping methods are being sought to

provide better selectivity for  $\text{Fe}^{+3}$ . The method of hydrolytic stripping removes iron as  $\text{Fe}_2\text{O}_3$  precipitate by contacting a loaded carboxylic acid with  $\text{H}_2\text{O}$  at  $130^\circ\text{C}$  to  $200^\circ\text{C}$  [17]. Similar to the hydrolytic stripping, the method of precipitation stripping is conducted with a dilute acid at  $100^\circ\text{C}$  to produce  $\text{FeOOH}$  precipitates. However, D2EHPA appears to be too acidic to use these two methods [18]. The use of  $\text{SO}_2$  in the aqueous phase increases the stripability of iron by reducing iron to  $\text{Fe}^{+2}$  allowing more  $\text{Fe}^{+3}$  to strip [19]. Some disadvantages of using  $\text{SO}_2$  include elevated operating pressure and temperature and the need to remove dissolved  $\text{SO}_2$  from the organic with water washes or 3%  $\text{H}_2\text{O}_2$  prior to reuse. Hydrogen stripping recovers iron as a metallic powder on colloidal carbon in the presence of  $\text{NH}_3$  from Versatic acid [20, 21]. In D2EHPA,  $\text{Fe}^{+3}$  is reportedly reduced to  $\text{Fe}^{+2}$  in the organic phase by  $\text{H}_2$  at  $101^\circ\text{C}$  and 2.76 MPa [22]. Some disadvantages of using hydrogen are the elevated operating temperature and pressure and the need for a hydrogen activation catalyst, such as nickel powder. However,  $\text{Fe}^{+2}$  is easily stripped with a dilute acid.

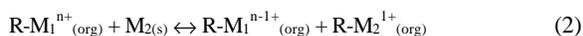
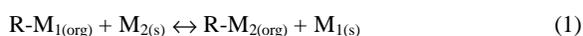
### ***Galvanic stripping***

In contrast to the problems observed with stripping  $\text{Fe}^{+3}$ , the  $\text{Fe}^{+2}$  is readily removed from loaded solvents in a relatively straightforward manner. Galvanic stripping provides a means to reduce the iron using ambient pressure and temperature [23-29]. Galvanic stripping involves the use of solid metals as the reductant directly in the loaded organic to allow the contained metal ions to be more easily removed. The procedure is essentially an electrochemical alternative to conventional chemical stripping of the

organics commonly used in the solvent extraction processing of metals. A brief review of the process and some results obtained to date will be given.

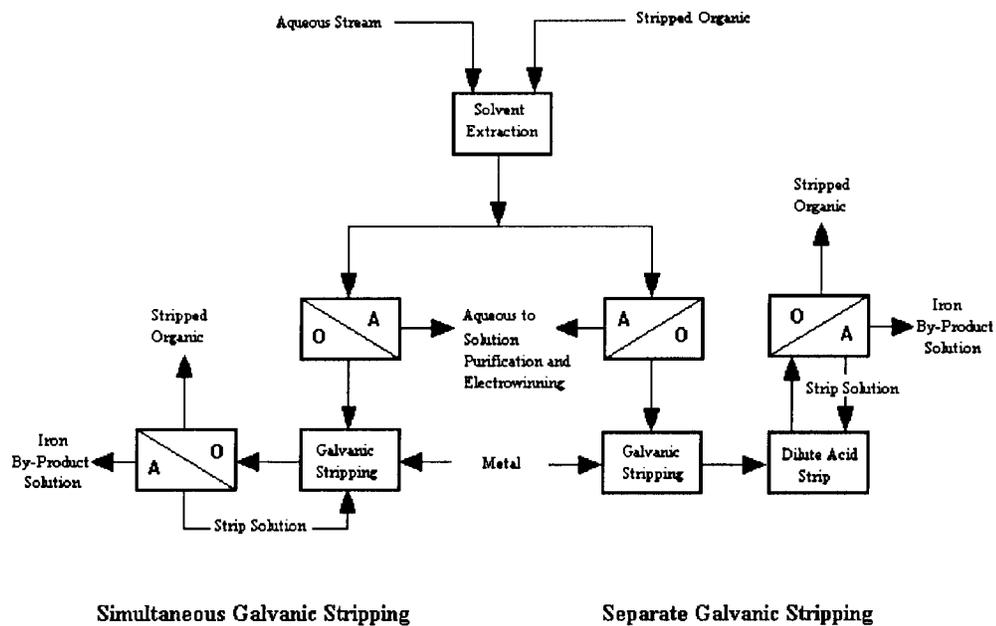
## **PROCESS DESIGN**

The format to describe aqueous displacement reactions can be adopted to express the galvanic stripping reactions. Two primary variations, in generic form, which express complete reduction and redox reactions are respectively,

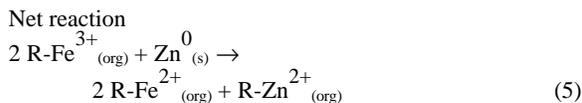
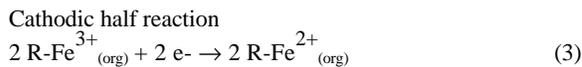


The  $\text{M}_1$  represents the cation in the organic to be removed and  $\text{M}_2$  represents the solid metal used as reductant. The R in this study is Di-2-Ethylhexyl phosphoric acid (D2EHPA). The two alternatives can be applied in galvanic stripping practice either individually or combined, depending on the system chemical composition.

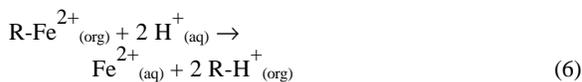
Since galvanic stripping is an electrochemical reaction, half-reactions, anodic and cathodic, can be employed to express the reaction. In this study, the reduction of  $\text{Fe}^{3+}$  to  $\text{Fe}^{2+}$  serves as the cathodic step, a redox type reaction. Thus a two-step procedure is identified in a galvanic stripping application: reducing the metal ions directly in the organic solvent and removing the reduced form of the metal. In the case of iron, this can be accomplished because of the fact that stripping  $\text{Fe}^{2+}$  with a dilute acid, which is not achievable with  $\text{Fe}^{3+}$ , is feasible due to the lower stability of ferrous ions in D2EHPA. The overall reaction for the reduction of ferric iron by zinc can be written as:



**FIGURE 1. GALVANIC STRIPPING FLOWSHEET**



After reduction, a dilute acid stripping is utilized to remove Fe from the organic to the aqueous solution as shown:



Either batch or continuous flow procedures could be employed in the process design. Then two other variations are available: separate or simultaneous stripping, as illustrated in Figure 1. The designs differ by having the reduction occur in the organic prior to the stripping step in a two-stage reaction sequence, or accomplishing both steps simultaneously by contacting the

organic, aqueous, and metal reductant phases together. Previous studies [27-29] indicate that simultaneous stripping shows higher efficiency for some redox type reactions. However, the separation of three phases—organic and aqueous phases and solid metal reductant—in simultaneous stripping might require a more sophisticated design than separate stripping.

The packed bed process may offer another alternative for a continuous flow procedure. This technique is accomplished by flowing the liquid over the fixed metal particles so that the stream can be treated continuously without settling for redox reactions. However, the operating parameters for such a process have to be optimized to obtain satisfactory rates and efficiencies for continuous operation.

## APPLICATIONS

Studies on a variety of solvents, diluents, metal ions, and metallic reductants has been made and a summary given in Table 3. The

purpose of the evaluation was to establish the feasibility or relative thermodynamic stabilities of the metal-ion-organic combinations. Since these tests were qualitative in nature, some systems were then chosen for a more detailed and quantitative study, with attempts made to define reaction rates and controlling mechanisms. Several factors which can affect the rate, efficiency, and stoichiometry (moles of reducing agent to moles of reduced ions) of galvanic stripping have been identified. These include oxygen potential, temperature, H<sub>2</sub>O content of the organic, agitation, reductant surface area, A/O ratio, and relative pH. More details will be discussed later.

In general, the results demonstrated that a broad range of organic-metal ion-metal

reductant systems would support galvanic stripping reactions.

### *Qualitative studies*

D2EHPA (from Albright & Wilson) was used as the extractant in a study to evaluate the behavior of the Fe<sup>3+</sup>/Fe<sup>2+</sup> system to galvanic stripping. Several reducing agents, such as powders of SHG Zn, Zn alloyed with Pb, Fe, and 1018 steel shavings, were employed to reduce Fe<sup>3+</sup>. Some Zn powders, coated with Pb, Au, and Cd, were also evaluated for Fe<sup>3+</sup> reduction. The results indicate, with appropriate operating conditions, that these metallic reductants are feasible options for use (Table 4). However, because of the possible cathodic enhancement from local sites of Pb on the Zn particle surface, the Zn alloyed with Pb

**TABLE 3. GALVANIC STRIPPING OF VARIOUS ION/METAL/ORGANIC SYSTEMS.**

| Extractant                | Cation                             | Loading Anion | Metallic Reductant |
|---------------------------|------------------------------------|---------------|--------------------|
| Organic Cementation       |                                    |               |                    |
| D2EHPA                    | Ag <sup>1+</sup>                   | Nitrate       | Al, Fe, Zn         |
|                           |                                    | Sulfate       | Al, Cu, Zn         |
|                           | Cd <sup>2+</sup>                   | Sulfate       | Zn                 |
|                           | Co <sup>2+</sup>                   | Sulfate       | Mn, Zn             |
|                           | Cu <sup>2+</sup>                   | Sulfate       | Cd, Fe, Zn         |
|                           | Pb <sup>2+</sup>                   | Chloride      | Zn                 |
|                           |                                    | Nitrate       |                    |
| Sn <sup>4+</sup>          | Chloride                           | Zn            |                    |
| D2EHPA + TBP              | Au <sup>3+</sup>                   | Chloride      | Al, Cu, Fe, Zn     |
|                           | Cu <sup>2+</sup>                   | Chloride      | Al, Zn             |
|                           |                                    | Fluoride      |                    |
|                           |                                    | Sulfate       |                    |
| Aliquat <sub>TM</sub> 336 | Au <sup>3+</sup>                   | Cyanide       | Zn                 |
|                           | Cu <sup>2+</sup>                   | Chloride      | Al, Cd, Zn         |
|                           |                                    | Sulfate       |                    |
|                           | Ni <sup>2+</sup>                   | Sulfate       | Fe, Zn             |
| LIX <sub>TM</sub> 864     | Cu <sup>2+</sup>                   | Chloride      | Zn                 |
| LIX <sub>TM</sub> 984     | Cu <sup>2+</sup>                   | Sulfate       | Zn                 |
| Redox Reaction Stripping  |                                    |               |                    |
| D2EHPA                    | Fe <sup>3+</sup> /Fe <sup>2+</sup> | Chloride      | Fe, Zn             |
|                           |                                    | Sulfate       |                    |
| TBP                       | Ce <sup>4+</sup> /Ce <sup>3+</sup> | Nitrate       | Cu, Zn             |

as reductant showed the most promise for Fe removal by galvanic stripping. Because of this, some evaluations were then made by adding Pb ions to the solution with SHG Zn to activate the metal *in situ*. Similar effects were achieved by using the alloy or surface activation.

Different kerosene diluents were used to evaluate their effect on galvanic stripping. The concentration ratios, particularly paraffin content, seemed to affect the recovery of iron. Proper selection of the diluent should be considered and may be more critical in galvanic stripping than conventional solvent extraction operations.

Some morphology studies of the reductant surface were made by SEM and EDX. In some of the cases, when reactions passivated after a period of time, a layer of Fe was found on the surface of reductant particles. It indicates that, instead of being reduced to  $Fe^{2+}$ , complete reduction to metallic iron onto the reductant surface can be obtained in certain situations. It is also possible that iron cementation might be some intermediate reaction in the  $Fe^{3+}/Fe^{2+}$

reduction, and the reaction decreases at this point due to a kinetic shift. Although iron cementation is a way to remove Fe, the Fe layer build-up on the reductant surface might block the anodic reaction and eventually passivate the whole process. In other cases where passivation occurred, phosphorus was found, which is probably from the extractant D2EHPA, which formed a precipitate on the surface of the reductant. This undesirable degradation of D2EHPA, in certain situations, is not only detrimental to reuse of, but also blocks the anodic reaction. Identifying and eliminating the source of these precipitates is necessary and studies are being conducted.

### *Quantitative studies*

Several operating variables were evaluated to identify their effect on galvanic stripping. Of primary interest was the influence of these variables on the efficiency and rate of iron removal.

### *Oxygen effect*

The influence of oxygen on iron removal is at two extremes. It is beneficial in helping to initiate zinc dissolution, but its presence is detrimental to process efficiency because of re-oxidation of the ferrous ions. However, the level of oxygen needed or that can be tolerated depends on the metal reductant used. For example, a relatively high sensitivity to oxygen content is experienced using 1018 steel as reductant, compared to Zn. Thus the level of oxygen needed to optimize the zinc dissolution and iron re-oxidation reactions must be determined for each individual set of parameters.

### *Temperature*

Increasing temperature increases the rate of iron removal; however, the degree of influence varies with reductant. Zn alloyed

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**TABLE 4.** THE EFFECT OF Pb IONS IN D2EHPA ON IRON REMOVAL USING SIMULTANEOUS STRIPPING.

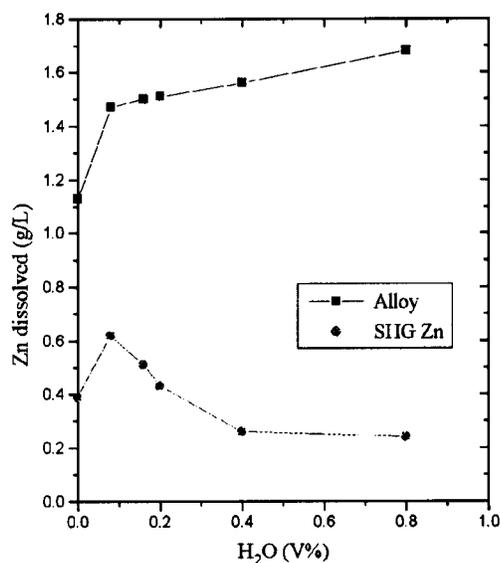
| Metal Reductant  | Fe Removal % |
|--|--------------|
| SHG Zn   | 51           |
| Fe   | 53           |
| Pb <sup>2+</sup> loaded in D2EHPA with SHG Zn as reductant | 70           |
| Pb <sup>2+</sup> loaded in D2EHPA with Fe as reductant     | 79           |

\*Test conditions: 5 minutes N<sub>2</sub> sparged prior to test and 15 minutes reaction at ambient temperature for all reactions. 15 g/l reductant, -100#,+200#, A/O=1 for tests SHG Zn used and 50 g/l reductant, -100#,+200#, A/O= 4 for tests Fe used.

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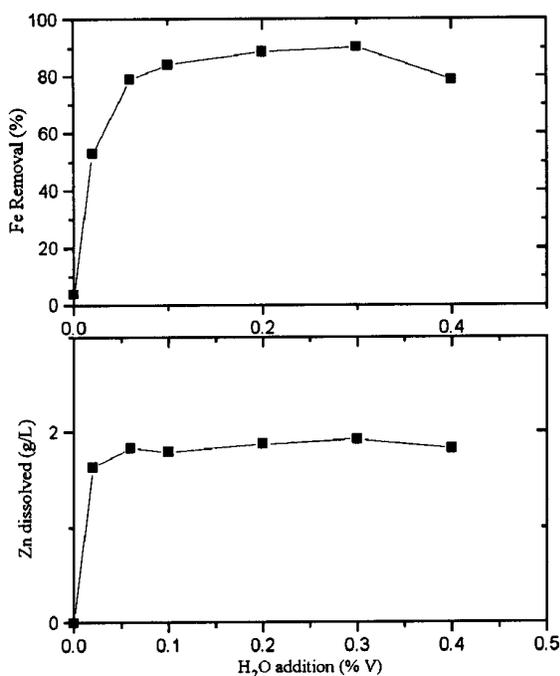
**FIGURE 2.** THE EFFECT OF H<sub>2</sub>O ON Zn-Pb ALLOY AND Zn SELF DISSOLUTION. (Zn-1.67% Pb ALLOY AND SHG Zn 0.1 G, -100#, +200#, 10% D2EHPA 10 ml [FILTERED], 1 HOUR REACTION, MEDIUM AGITATION, AMBIENT TEMPERATURE.)

with Pb gives the highest rate of iron removal, so increased temperature becomes less significant than for other reductants.

### H<sub>2</sub>O effect

The H<sub>2</sub>O content in the organic has a major influence on the anodic reaction of galvanic stripping which depends on the dominant cathodic reaction. The effect of H<sub>2</sub>O additions on Zn-Pb alloy self dissolution is shown in Figure 2. Without Fe<sup>3+</sup> in the organic, hydrogen evolution is apparently the cathodic reaction, and the water content shows a constant positive effect on the self dissolution of Zn-Pb alloy but a passivating effect using SHG Zn if excess water was added.

In Figure 3, the results of anodic zinc dissolution and iron removal from 30V% D2EHPA by separate stripping using Zn-Pb alloy, as a function of water addition, is



**FIGURE 3.** THE EFFECT OF WATER ADDITION ON SEPARATE STRIPPING. (1.67% Pb-Zn ALLOY, -100+200#, 5 MIN N<sub>2</sub> SPARGED PRIOR TO REDUCING STAGE, 30 MIN REACTION FOR BOTH STAGES, 20 g/l H<sub>2</sub>SO<sub>4</sub> AS STRIP SOLUTION, AMBIENT TEMP.)

shown. In the presence of ferric ions, the dominate cathodic reaction shifts to ferric reduction and the data show that the water content of the organic had a significant effect on the anodic zinc dissolution reaction and thus affects iron removal, especially when the oxygen content in the organic is low. However, the rate of iron removal does not increase as more water is added, indicating that effect of water content is more on initiating the reaction than for activating the reaction continuously. Furthermore, other tests show that iron removal using SHG Zn as the reductant had not been passivated when more water was added, unlike the effect observed for zinc self dissolution when iron is not present in the organic. Thus, the need to maintain a

proper level of water and oxygen in the organic is evident.

### ***Agitation***

In previous studies [27], the mechanism of iron removal was determined to be under mixed chemical and diffusion control in the range of 30° to 50°C respectively, as indicated by the calculated activation energies. However, the experiments suggested that chemical rather than diffusion control was more probable because degree of agitation did not make any difference in iron removal. However, increased mixing did cause more zinc to dissolve, indicating that the anodic zinc dissolution reaction does have a diffusion control component in the mechanism. Similar reaction rates were also obtained using different forms of agitation, such as ultrasonics, so the method used to enhance the mass transport does not seem to be at issue.

### ***Reductant surface area***

The rate and stoichiometry of iron removal can be greatly improved by using more reductant surface area. Furthermore, the oxygen effect might be diminished by using higher surface area of metal reductant. This aspect eventually leads to an easier

optimization and makes the continuous packed bed process more promising.

### ***pH effect***

The pH of the aqueous strip solution is the major controlling factor in the zinc and iron ion exchange between organic and aqueous phases. The effect of pH of the strip solution and A/O ratio on iron and zinc removal in galvanic stripping are shown in Table 5. Carefully controlling the initial pH to obtain a desired final pH of strip solution can result in a relatively pure strip solution. This is important if the iron strip solution is to be of commercial value. The A/O ratio, volume ratio of aqueous strip solution to organic extractant, is another alternative method to control strip solution pH. However, it is probably easier to control the A/O ratio to achieve the desired final pH of strip solution.

## **CONCLUSIONS AND FUTURE DEVELOPMENT**

The unique aspect of the galvanic stripping process is the use of solid metal reducing agents to accomplish spontaneous electrochemical reactions in organic media. This is somewhat unexpected because the organics used are not good electrolytic conductors. One particularly attractive use is

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**TABLE 5.** THE EFFECT OF pH OF STRIP SOLUTION AND A/O RATIO ON IRON AND Zn REMOVAL IN GALVANIC STRIPPING.

| Test Conditions                             | Final pH | Fe Removal % | Zn Stripped % |
|---|----------|--------------|---------------|
| Initial pH of strip solution = 0.34, A/O =1 | 0.61     | 91           | 52            |
| Initial pH of strip solution = 0.34, A/O =3 | 0.42     | 99           | 86            |
| Initial pH of strip solution = 1.11, A/O =1 | 2.06     | 62           | 3             |
| Initial pH of strip solution = 1.11, A/O =3 | 1.51     | 95           | 11            |
| Initial pH of strip solution = 1.4, A/O =1  | 2.6      | 38           | 0             |
| Initial pH of strip solution = 1.4, A/O =3  | 2.07     | 80           | 2             |

\*simultaneous stripping, 30% D2EHPA loaded with 8.2 g/l Fe<sup>3+</sup>, 50 g/l SHG Zn reductant (-60#, +100#), medium agitation, 1 minute N<sub>2</sub> sparged, 40°C, 10 minutes reaction, acidified FeSO<sub>4</sub> solution

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in separating iron from zinc. Reducing the iron makes the separation possible because the  $\text{Fe}^{2+}$  can be stripped into a higher pH solution which strips neither  $\text{Zn}^{2+}$  nor  $\text{Fe}^{3+}$ . These combinations are the features which make galvanic stripping a technically feasible option to treat oxidized iron-zinc residues.

In summary, galvanic stripping does seem to offer promise as a major component in the solvent extraction treatment of zinc neutral leach residues. Both batch type processes, simultaneous and separate stripping, and a continuous flow procedure, packed bed process, are possible design options. Qualitative and quantitative laboratory studies show that a variety of chemical process combinations of reductants, diluents, and solvents are possible. System optimization requires a knowledge of oxygen potential, temperature,  $\text{H}_2\text{O}$  content of the organic, agitation, reductant surface area, A/O ratio, and relative pH for best overall efficiency.

The unique galvanic stripping process has demonstrated some interesting chemical process options, many of which may be particularly applicable for the treatment of a variety of hazardous metal bearing wastes.

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