EXTRACTION OF ZINC METAL FROM ZINC ORE USING PILOT PLANT UNIT

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ABSTRACT

Extraction of zinc metal from zinc ore was carried out using a pilot plant of about 17 kg/hr zinc metal capacity. A computer program was developed for calculation of feeding and production rates. The results obtained show that recovery of about 87% of zinc is achieved using 100% -100 mesh ore particle size at a reaction temperature of 50 °C for 3 hr total retention time and about 22% solid content. About 2/3 of sulfuric acid used was regenerated during electrolysis of zinc sulfate pregnant liquor. Material and zinc component mass balances for whole process were calculated. For production of 1 ton zinc metal, about 5.62 ton zinc ore, 0.95 ton 98% make-up sulfuric acid and 4.26 m^3 wash water are required. In addition, the distributions of impurities were calculated. It was found that most of magnesium (about 96%) dissolves and transfers to zinc sulfate pregnant solution. Novel technique was applied for magnesium sulfate removal.

Keywords

Mineral processing; leaching; recycling; material balance; component mass balance

INTRODUCTION

Depletion of high-grade ores and/or increasing the demand for metals all over the world has necessitated intensive studies for extraction of metals from low-grade ores. Extraction of zinc can be performed either by hydrometallurgical or pyrometallurgical routes. Hydrometallurgical processing of zinc silicate ores is becoming more attractive due to depletion of zinc sulfide ores as well as restriction on sulfur emissions during their processing (Caiqiao and Wanwei, 1988, Dufresne, 1967).

In Egypt, zinc ore deposits are present on the Red sea coast between Qusseir in the north and Ras Benas in the south. The total reserves are estimated as 1.5 million tons (Shukry, 1994).

However, extraction of zinc metal or zinc salts from these ores on industrial-scale is not yet established. Recently, there is a plant for production of zinc metal and zinc sulfate from industrial zinc dross (ash) near Cairo. It was reported that, about 350 ton/year of zinc dross are wasted in only 2 Egyptian companies (EL-Nasr Steel Tubes and Iron &Steel) (Arafa, et al., 1987). Moreover, the Aluminum Company of Egypt (Egyptalum) has established a pilot plant for extraction of about 17 kg/hour zinc metal from zinc silicate ore (Shukry, 1994).

In industry the leaching process is performed in a cascade reactor unit comprising two stainless steel reactors. Sulfuric acid is fed to the first reactor. The reaction is exothermic and the temperature rises without heating to 70 °C in the first reactor (Huggare et. al., 1973). The Vielle-Montage process utilizes a series of leaching vessels in which the acidity is progressively increased at a temperature between 70 °C and 90 °C for 8 to 10 hours retention time (Bodson, 1976). In addition, there are different leaching regimes depending on amount and nature of impurities (e.g. neutral leaching followed by acidic leaching) (Newton, 1959). Then, the solution is separated from the solid material in a concrete thickener lined with glass (Huggare et. al., 1973).

The optimum leaching conditions of Egyptian zinc ore from Umm-Geig area, Eastern Desert (Egypt) with sulfuric acid were reported (Abdel-Aal, 1997). The obtained leaching conditions are 100% -200 mesh ore particle size, 50 °C reaction temperature, 2 hr leaching time, 1:3 g/ml solid/liquid ratio, 1.58:1 stoichiometric molar ratio of H_2SO_4:Zn and 15.6% acid concentration (Abdel-Aal, 1997). In addition, kinetics studies of sulfuric acid leaching of Umm-Geig zinc ore was reported (Abdel-Aal, 2000). A major obstacle to hydrometallurgical treatment of zinc silicate ore is handling of silica gel produced in an acid leach. This silica ordinarily enters solution along with the zinc as colloidal silicic acid which occludes zinc values and makes filtration difficult if not impossible (Caiqiao and Wanwei, 1988). Specialized six techniques as well as a novel one for solving this problem were reviewed (Abdel-Aal, 1997). Also, another approach to solve silica gelation problem by quick leaching of Umm-Geig zinc ore with sulfuric acid was reported (Abdel-Aal and Shukry, 1997).

This paper presents the results of sulfuric acid leaching of Egyptian zinc silicate ore on pilot plant as well as the distributions of the impurities between the liquid and solid phases.

Filtration rate of the zinc sulfate solution was followed with and without addition different proportions of Al powder. Material and zinc component mass balances are also presented.

EXPERIMENTAL

Materials and equipment

Zinc silicate ore from Umm-Geig area, Eastern Desert (Egypt) was used. It was characterized elsewhere (Abdel-Aal, 1997). It contains hemimorphite [$Zn_4Si_2O_7(OH)_2.H_2O$] and willemite [Zn_2SiO_4] as major minerals as well as smithsonite [$ZnCO_3$], cerussite [$PbCO_3$], quartz [SiO_2], gypsum [$CaSO_4.2H_2O$] and geothite [$FeO(OH)$] as minor minerals (Abdel-Aal, 1997). The ore contains about 26.3% ZnO, 24.0% SiO_2, 13.3%Fe_2O_3, 5.9% PbO, 5.6% CaO, 3.4% Al_2O_3, 2.33% MgO, 0.92% MnO, 0.11% CdO and 0.0013% CuO (Abdel-Aal, 1997). The ore was ground to 100% -100 mesh.

Commercial sulfuric acid from Abu-Zabaal Fertilizers and Chemical Company (Egypt) was used in this study. It has concentration of 98% and density of 1.845 g/ml. The reaction between zinc ore and sulfuric acid was performed in 800 L effective volume of rubber lined reactor followed by neutralization in rubber lined tank of 400 L effective volume capacity. Complete description of the pilot plant is reported elsewhere (Shukry, 1994).

Procedure

To save time, a computer program is proposed for calculation the reactants feeding rates of the pilot plant. Summary of the calculated feeding and production rates of the pilot plant is given in Table (1). The average practical feeding and production rates are consistent with the calculated values within less than 3% standard deviation. A simplified flow-sheet of the Zn extraction process is given in Fig. 1.

During the continuous operation of the pilot plant, the slurry is filtered using pan filter under vacuum. In parallel, slurry samples were filtered on laboratory using Buchner-type funnel. The residue was washed two times using wash liquors collected from the pilot plant washing streams and once using wash water. The filtrate and wash liquors were chemically analyzed for Zn. Filtration and washing times were recorded to calculate the filtration rate. The following filtration and washing conditions were applied:

Type of filter:	Buchner-type funnel
Diameter of filter:	15.2 cm
Filter area:	181.5 cm^2
Type of filter cloth:	Polypropylene
Aperture of filter cloth:	200 mesh
Pressure difference:	600 mm.Hg (23.6 inch.Hg)
Temperature of slurry:	70 °C

In this study, filtration rate is expressed as ton Zn produced per meter square per day and calculated by applying Equation No. (1):

$$F.R. = Z \times A \times F / T \qquad (1)$$

Where:

F.R.: Filtration rate, ton Zn/m^2.day

Z: Net wt. of extracted Zn in filtrate and wash liquors, g

A: Filter area, cm^2

F: Conversion factor

T: Total time of filtration, washing and drying, sec

Operating conditions:

Summary of the process conditions is given in Table (2). It is worthy of mention that, these conditions are obtained from laboratory experiments as well as from preliminary pilot runs (Shukry, 1994, Abdel-Aal, 1997). However, from economic point of view, coarser ore particle size (100% -100 mesh) was used rather than fine ore of 100% -200 mesh particle size.

RESULTS

Distribution of the impurities

Distribution of the impurities after leaching and neutralization stages was thoroughly traced. The results obtained which are given in Table (3) reveal that most of Mg (96.3 %) and Cd (53.45%) were dissolved in zinc sulfate liquor. From the other hand, more than 98% of Fe, Si, Mn, Pb, Al and Ca impurities are precipitated and remain in residue. During continuous operation of the pilot plant, dissolved magnesium sulfate is accumulated in the spent liquor. To prevent this accumulation, a bleed from third wash liquor (33%) was taken and neutralized with CaO till pH 7. Zinc is precipitated as basic zinc sulfate $3Zn(OH)_2.ZnSO_4$ which was filtered and recycled to the neutralizer. On the other hand, magnesium sulfate solution is discarded as industrial waste. It can be used as micro nutrients liquid fertilizer.

Filtration rate

Results of filtration rate measurement during steady state periods of continuous operation with and without Al powder are given in Fig. 2. Al powder was added in the range of 0.1% to 0.5% related to the ore weight. The obtained filtration rate values are nearly constant with time. Moreover, addition of Al powder significantly increases the filtration rate. The optimum Al powder dosage is 0.3%. Al powder reacts with free sulfuric acid to form aluminum sulfate. Al^{3+} ions decrease the solubility of silica, preferentially adsorb on the colloidal silica surface and coagulate them rendering to higher filtration rate (Perry, 1996, Wood et. al., 1977, Kumar and Biswas, 1986).

Comparison of filtration rates from this study with filtration rates from previous lab.-scale study (Abdel-Aal, 1997) is given in Fig. 3. The results show that with increasing percentage of Al powder, the filtration rates of zinc sulfate solutions of both lab.-scale and pilot plant are increased. However, lower filtration rates were encountered during the pilot plant operation. This is attributed to using spent electrolyte for reaction. Concentration of Zn in filtrate from lab.-scale study was 72 g/L (Abdel-Aal, 1997) compared with 110-130 g/L in this study. Higher zinc sulfate concentration increases the viscosity and reduces the filtration rate.

Material balance

Material balance as well as Zn component mass balance for processing of zinc ore is given in Table (4). In addition, the consumption pattern based on production of 1 ton Zn metal is given in Table (5). For production of 1 ton zinc metal, about 5.62 ton zinc ore, 0.95 ton 98% make-up sulfuric acid and 4.26 m^3 wash water are required. Beneficiation of this ore is required to reduce sulfuric acid consumption, reduce the solids to be filter, increase the filtration rate and decrease zinc sulfate losses in residue.

CONCLUSIONS

Leaching of low-grade zinc ore with sulfuric acid was continuously tested on pilot plant. Extraction efficiency of about 87% of the zinc present in the ore was achieved under the following conditions: particle size 100% -100 mesh, reaction temperature 50 °C, neutralization temperature 70 °C and total reaction time 3 hr. From material balance calculations, it was found that about 5.62 ton zinc ore, 0.95 ton 98% make-up sulfuric acid and 4.26 m^3 wash water are required for production of 1 ton zinc metal.

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Table (1): Summary of Feeding and Production Rates for the Pilot Plant

Rate	kg/hr
Feeding	
Zinc ore for reaction	96.0
Zinc ore for neutralization	4.8
98% Sulfuric acid	17.1
Wash water	76.4
CaO	0.48
Zn dust	0.24
Production	
Zinc metal	17.9

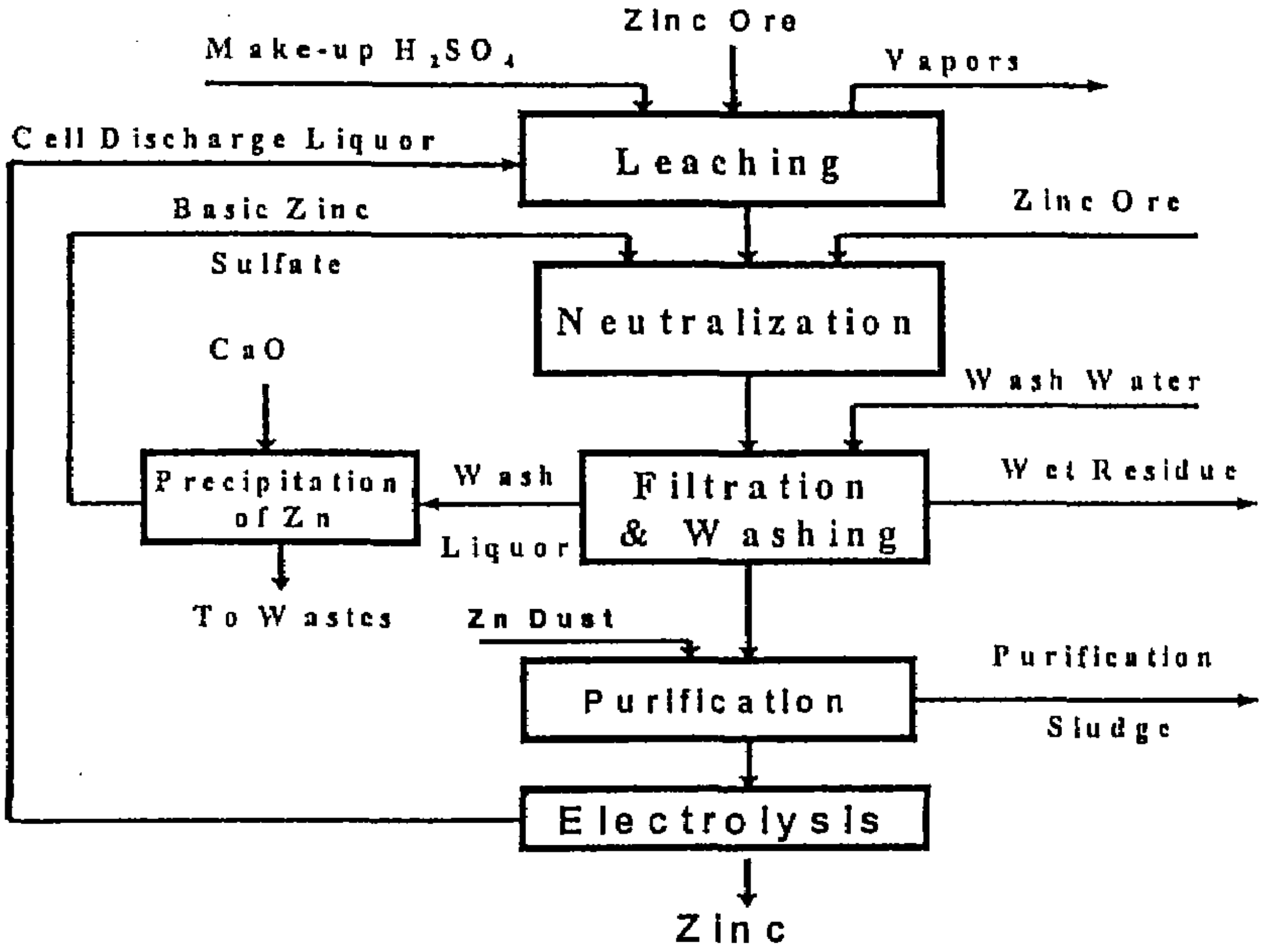

Fig. 1. Simple Flow-sheet of Zn Extraction Process

Table (2): Summary of the Operating Conditions

Operating Conditions	Range	Average Value
Reaction temperature, °C	48-52	50
Neutralization temperature, °C	68-72	70
Reaction time, hr	2.0	2.0
Neutralization time, hr	1.0	1.0
Total retention time, hr	3.0	3.0
Neutralization pH	4.0-4.5	4.25
Solid content, %	21.0-23.4	22.2
Slurry density, g/ml	1.40-1.50	1.40
Zn content in pregnant liquor, g/L	110-130	120
Density of pregnant liquor, g/ml	1.24-1.32	1.28
Zn content in cell discharge liquor, g/L	40-60	50
Free H_2SO_4 content in cell discharge liquor, g/L	100-150	125
Density of cell discharge liquor, g/ml	1.18-1.26	1.22

Table (3): Distribution of Zinc Ore Impurities after Leaching and Neutralization

Component	Relative Distribution, %		
	Zinc Ore	Zinc Sulfate Liquor	Residue
Fe	100	0.01	99.99
Si	100	0.02	99.98
Mn	100	0.68	99.32
Pb	100	1.11	98.89
Al	100	1.29	98.71
Ca	100	1.87	98.13
Cu	100	5.79	94.21
Cd	100	53.45	46.55
Mg	100	96.30	3.70

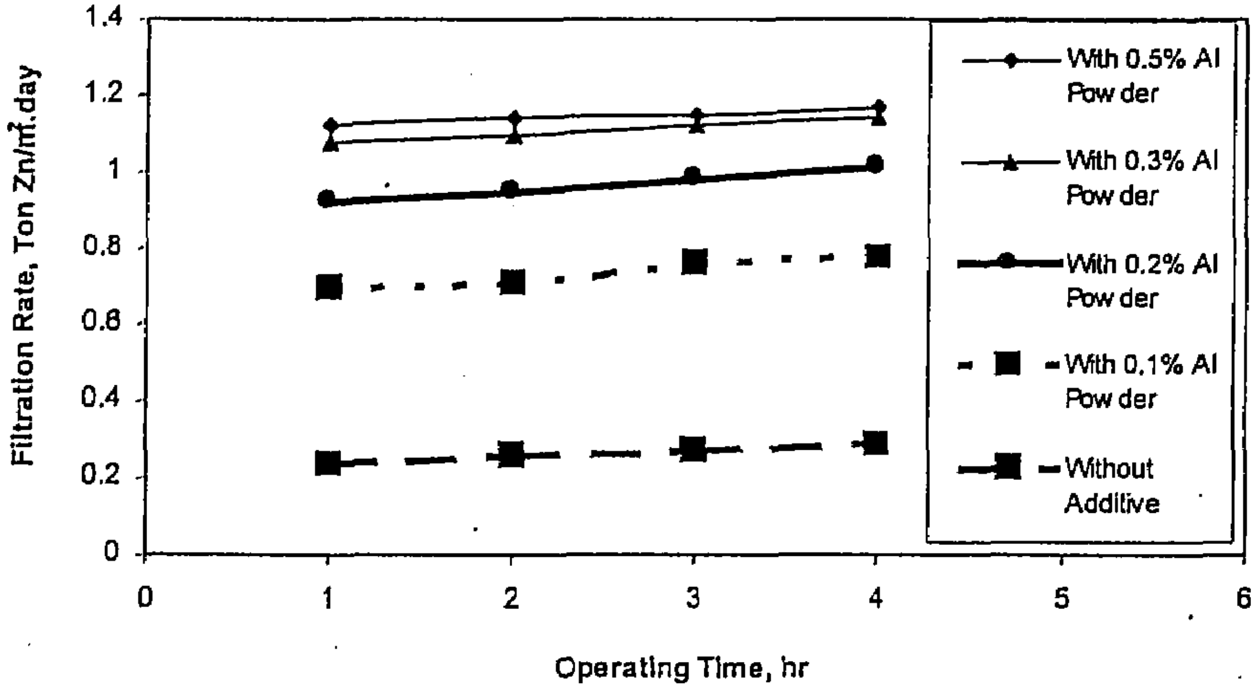

Fig. 2. Effect of Operating Time and Amount of Al Powder on the Filtration Rate of Zinc Sulfate Solution

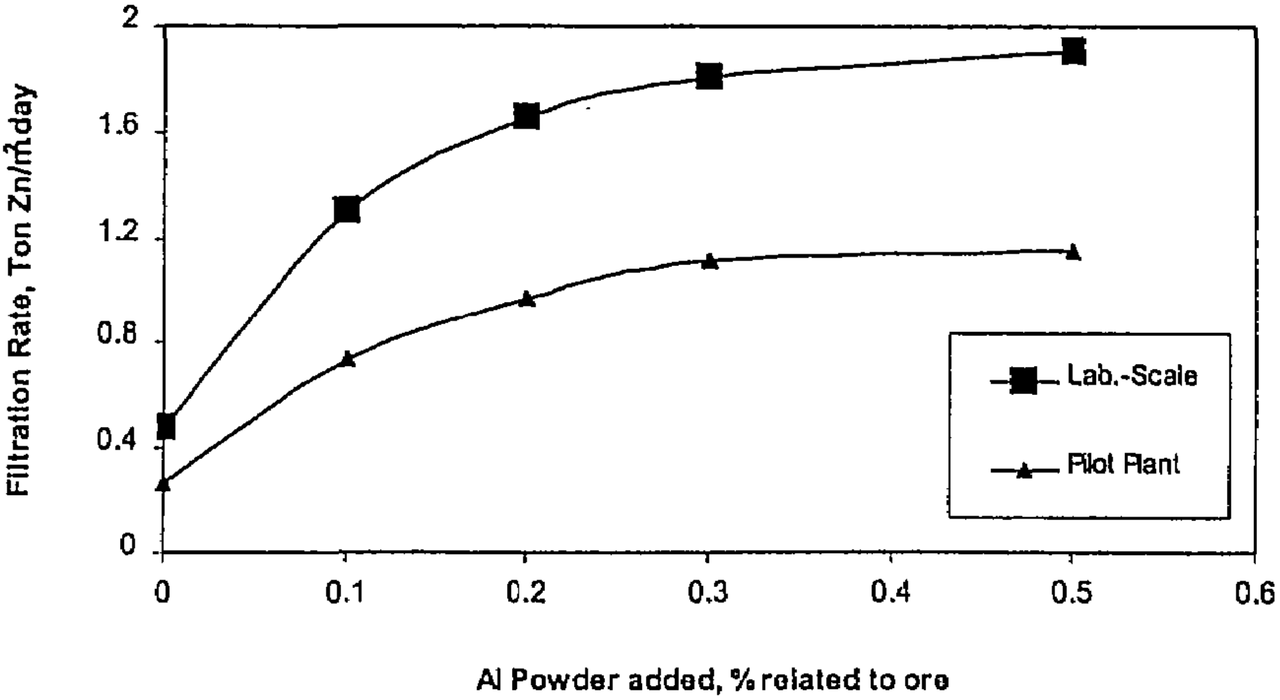

Fig. 3. Effect of Al Powder on Filtration Rate of Zinc Sulfate Solution
Lab.-scale data from Ref. No. 8.

Table (4): Material Balance for Extraction of Zinc Metal from Zinc Silicate Ore

1. Leaching:

Input	Amount, Kg		Output	Amount, Kg	
	Mass	Zinc		Mass	Zinc
Zinc ore	1000.0	204.0	Leaching slurry	4132.7	333.0
Sulfuric acid	178.1	0.0	Vapors	202.2	0.0
Cell discharge liquor	3156.8	129.0			
Total	4334.9	333.0	Total	4334.9	333.0

2. Neutralization:

Input	Amount, Kg		Output	Amount, Kg	
	Mass	Zinc		Mass	Zinc
Leaching slurry	4132.7	333.0	Neutralization slurry	4091.6	345.7
Zinc ore	50.0	10.2	Vapors	101.1	0.0
Basic zinc sulfate	10.0	2.5			
Total	4192.7	345.7	Total	4192.7	345.7

3. Filtration, washing and precipitation of zinc:

Input	Amount, Kg		Output	Amount, Kg	
	Mass	Zinc		Mass	Zinc
Neutralization slurry	4091.6	345.7	Pregnant liquor	3346.0	315.5
Wash water	795.8	0.0	Wet residue	1263.6	27.7
CaO	5.0	0.0	Basic zinc sulfate	10.0	2.5
			Wastes	272.8	0.0
Total	4892.4	345.7	Total	4892.4	345.7

4. Purification and electrolysis:

Input	Amount, Kg		Output	Amount, Kg	
	Mass	Zinc		Mass	Zinc
Pregnant liquor	3346.0	315.5	Zinc metal	186.9	186.9
Zinc dust	2.5	2.5	Cell discharge liquor	3156.8	129.0
			Purification sludge	4.8	2.1
Total	3348.5	318.0	Total	3348.5	318.0

Table (5): Consumption Pattern for Production of 1 ton Zn Metal

Consumed Materials	Amount
Zinc ore, ton	5.62
98% Sulfuric acid, ton	0.95
Wash water, m^3	4.26
CaO, kg	26.8
Zn dust, kg	13.3