Available online at www.sciencedirect.com
SCIENCE DIRECT
hydrometallurgy
Hydrometallurgy 83 (2006) 77–82
www.elsevier.com/locate/hydromet

Bacterial heap-leaching: Practice in Zijinshan copper mine ☆

Ruan Renman [a,*], Wen Jiankang [a], Chen Jinghe [b]

[a] General Research Institute for Nonferrous Metals, No. 2 Xinjiekuowai Street, Beijing 100088, China
[b] Zijin Mining Corporation Ltd., No. 277 Beihuan Str., Shanghang County, Fujian Province 364200, China

Available online 3 July 2006

Abstract

Zijinshan copper mine is the largest chalcocite deposit in China. The attempt to recover copper from the ore by bioleaching began at the end of 1998. Following the metallurgical studies carried out over 2 years, a pilot plant consisting of bio-heap leaching and SX–EW was built at the Zijinshan Copper Mine at the end of 2000, with a production capacity of 300 t/a copper cathode. After its successful operation for 1.5 years, the plant was scaled up to a capacity of 1000 t/a copper cathode by June 2002. Currently a commercial bio-heap leach plant with a capacity of 10,000 t/a is under construction and is scheduled to be commissioned by the end of 2005.

This paper describes metallurgical studies and pilot plant tests for Zijinshan Copper ore. A brief introduction to the mineralogy, bacterial culture, shake flask tests and column tests on bioleaching is presented. The performance of bio-heap leaching and SX–EW, acid and iron balance, operational cost of the pilot plant are discussed. A brief summary of the process flow sheet and the estimated capital cost of the commercial plant of 10,000 t/a are presented at the end of the paper.

Keywords: Chalcocite; Bio-heap leaching; Metallurgical studies; Pilot plant

1. Introduction

The Zijinshan copper deposit is located in Shanghang County, Fujian Province, with total secondary copper sulfide reserves of 240 million tons at an average grade of 0.63% total Cu. The copper sulfides are mainly chalcocite, covellite and enargite. Because of the low copper grade and arsenic content in the Zijinshan copper ore, the conventional route of flotation followed by concentrate smelting is no longer suitable.

The metallurgical studies including mineralogy, bacterial adaptation, shaking flask tests and column tests were carried out over 2 years commencing the end of 1998. A pilot plant consisting of bio-heap leaching and SX–EW was built at the Zijinshan copper mine by the end of 2000, with a production capacity of 300 t/a copper cathode. After operation for 1.5 years, the plant was scaled up to a capacity of 1000 t/a copper cathode by June 2002. Several modifications to the heap-leaching and the SX–EW process were made to improve the performance of the pilot plant. 80% copper recovery was achieved within 200 days by the year 2003. Currently, a plant with a capacity of 10,000 t Cu/a, the first commercial plant of bio-heap leaching in China, is scheduled to be

☆ Foundation item: Project (2001BA609A-17) supported by key Technologies R & D Program of China; Project (2004CB619206) supported by the state key Fundamental R & D Program of China ("973").
* Corresponding author.
E-mail address: ryan@grinm.com (R. Renman).

0304-386X/$ - see front matter © 2006 Published by Elsevier B.V.
doi:10.1016/j.hydromet.2006.03.048

Table 1
Chemical composition

Elements	Cu	S	Fe	As	SiO_2	Al_2O_3	CaO	K_2O	Na_2O	MgO
Composition (%)	0.65	2.60	2.43	0.038	59.99	10.84	0.46	0.067	0.039	0.055

Table 2
Minerals composition

Minerals	Pyrite	Chalcocite	Covellite	Energite	Quartz	Alum	Dickite
Composition (%)	5.80	0.65	0.40	0.16	65	12	15

started up at the Zijinshan Copper Mine by the end of 2005.

Zijinshan copper mine is located in a subtropical region. The average atmospheric temperature at the mine is 16 °C–20.3 °C; the lowest temperature in winter is −2 °C and the highest in summer is 38 °C. The annual rainfall is 1520–2130 mm. The warm weather is favorable to bioleaching, but high rainfall is a challenge to the heap-leaching operation. High pyrite content provides the main source of sulphuric acid and ferrous ions, while a small amount of acid consuming gangue minerals is present. Accumulation of acid and ferric ions is a big challenge to the heap leaching–SX–EW for the Zijinshan copper ore. The results of the pilot plant show that the process of heap leaching–SX–EW works well at Zijinshan copper mine, but water balance, acid balance and iron balance remain challenges to the commercial plant.

A description of mineralogy and bioleaching for Zijinshan copper ore may be found elsewhere [1–3]. This paper mainly reviews the pilot plant tests [4] together with a brief introduction of the laboratory tests and the commercial plant [5].

2. Mineralogy

The copper sulfides are mainly chalcocite, covellite and enargite and gangue minerals are quartz, dickite, and sericite (fine grained mica). Table 1 describes the chemical composition of the ore and Table 2 shows the mineral composition. The analytical method to establish quantitative mineralogy is SEM. Head assay was used to separately quantify oxide and secondary sulfide copper minerals from chalcopyrite. It involves dissolution of pulverized ore samples in 50 g/L sulfuric acid solution for a period 2 h to quantify oxide copper minerals and in 3 wt.% sodium cyanide solution for a period 4 h to quantify secondary sulfide copper minerals. The results of head assay are presented in Table 3.

Table 3
Head assay result

	AS–Cu	CNS–Cu	Total Cu
Cu (%)	0.05	0.57	0.64

3. Bacterial culture

The mesophilic bacterial culture used in laboratory tests and pilot plant tests was sourced from the acid mine drainage of Zijinshan copper mine. Optimum growth occurs at pH 2.0–2.5 and 28–35 °C. After adaptation the culture can tolerate low pH value to 0.9–1.2.

Characterization of the culture from the pilot plant by analysis of 16SrDNA sequences indicated that strains of *Leptospirillum* and *Acidithiobacillus* appeared to be the principal iron/sulphur-oxidising bacteria. Heterotrophilic microorganisms (such as *mold*

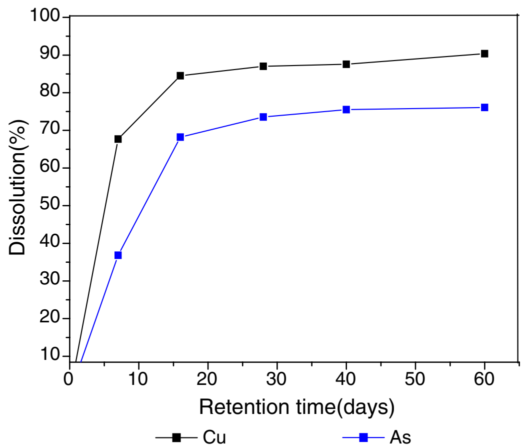

Fig. 1. Dissolution rates of Cu and As.

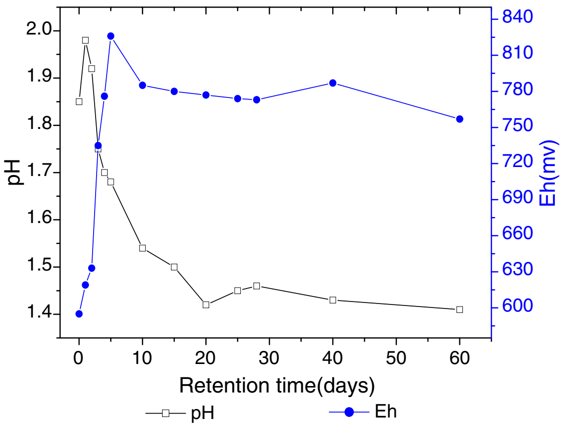

Fig. 2. Eh and pH.

and *yeast*) were found to occur in significant numbers in the culture from the leach heaps.

4. Shake flask tests

The ore sample for shake flask tests was ground to 88%–74 μm. After leaching for 28 days at 30 °C with the adapted mesophilic culture, 88% of copper and 73% of arsenic were dissolved. The dissolution rates of Cu and As are shown in Fig. 1. The profiles of Eh and pH are presented in Fig. 2.

5. Column leach tests

The column tests were carried out at ambient temperature ranging from 20 °C to 35 °C with the adapted mesophilic culture. The samples were crushed to −40 mm, −20 mm and −12 mm respectively to investigate the effects of particle size. The column in diameter of 262 mm, 2000 mm high was used for the

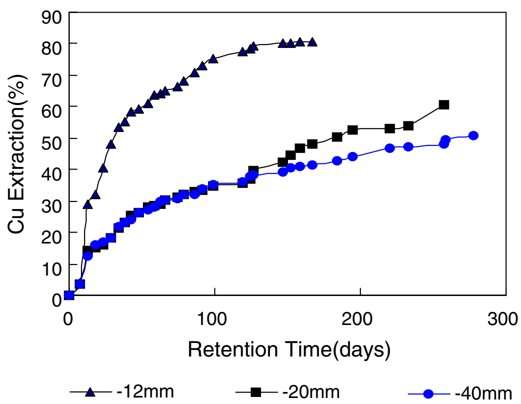

Fig. 3. Column bioleaching with the mesophile culture.

Table 4
Extraction from column leach residue

	Cu	Fe	S	As
Head ore (%)	0.65	2.43	2.60	0.038
Residue (%)	0.134	1.80	1.96	0.011
Extraction (%)	79.38	25.93	24.62	71.05

sample of −40 mm, the column in diameter of 150 mm, 1300 mm high for the sample of −20 mm, and the column in diameter of 120 mm, 1200 mm high for the sample of −12 mm. The irrigation rate at 24–40 L/m^2/h was applied to the column leach. The test results for different particle size fractions are shown in Fig. 3. The results indicate that a copper dissolution of 80% is attained at a residence time of 167 days for the −12 mm size fraction, but lower copper extraction is obtained for the sample of −40 mm and −20 mm. For the −12 mm size fraction, 70% As, 26% Fe and 25% S are dissolved when copper extraction reaches 80%, as shown in Table 4.

6. Pilot plant tests

The ore came from the underground mine and was crushed before being fed to the heap leach and SX–EW pilot plant. The mining and crushing systems, previously built and used for the flotation pilot plant, were modified for the bioleaching pilot plant. The pilot plant with production capacity of 300 t/a copper cathode consisted of two leach heaps, one solution collection and the SX–EW system. Pilot plant tests started up from January 2001. An overall plant view is shown in Fig. 4.

Copper sulphide ore from underground mine is crushed to −30 mm and −50 mm, respectively, and then transported by trucks to the leach heaps and stacked. 15,839 tons of ore, in size of −30 mm at an average grade of 1.12% total Cu, has been stacked to leach Heap 1, and 13,075 tons of ore in size of −50 mm at an average grade of 0.50% total Cu has been stacked to leach Heap 2. The lift height for each heap is 4.5 m. The adapted bacterial culture used in the column tests was cultivated in the pilot plant and used to inoculate the heaps during stacking. Wobblers supplied solution at an irrigation rate of 15–20 L/m^2/h, with a rest–rinse cycle, and a 3-day rest period every week. After leaching for 270 days, copper dissolution reached 80% for Heap 1 with particle size of −30 mm, and 65% for Heap 2 with particle size of −50 mm. The monthly solution chemistry of pregnant

Fig. 4. Overall view on 300 t/a pilot plant.

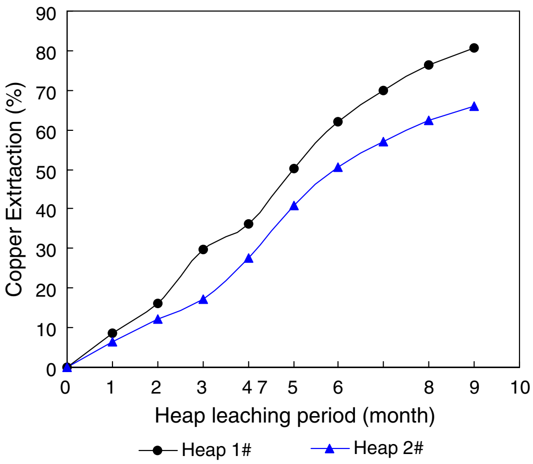

Fig. 5. Copper extractions of the 300 t/a pilot plant.

leach solution (PLS) and raffinate is shown in Table 5. Metal extractions calculated using solids analysis are presented in Table 6 and Fig. 5.

The SX unit was designed as a conventional 2E and 1S circuit (two-stage extraction and one-stage stripping). LIX 984N was selected as the copper extractant for Zijinshan. The copper recovery reached 75–80% in the initial period of 6 months and declined to 50% at the end of leaching circle of 9 months as pH value of PLS descends to 1.19. Fig. 6 shows the copper extraction by months. The chemistry of typical PLS and electrolyte is presented in Table 7.

Electrowinning is operating at a current density of 180 A/m^2 in 12 electrolytic cells. Each electrolytic cell contains 22 cathodes and 23 anodes. Current efficiency is around 85–90% and commonly 90% high grade cathodes are being stripped from stainless steel blanks, at a cathode weight around 40 kg each.

The pilot plant was scaled up to a capacity of 1000 t/a copper cathode by June 2002; several tests and improvements were made to optimize the plant operation.

- Leach heaps are stacked up to 10 m high with particle size of −30 mm. Copper recovery of Heap 3 is shown in Table 8. The results indicated that leach kinetics had improved. Copper extraction reached 80% within 200 days, which is better than that of first two heaps.

Table 5
Solution chemistry of PLS and raffinate

Date (2001)		Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.
Raffinate	Cu^{2+} (g/L)	0.61	0.62	0.62	0.64	0.37	0.28	0.31	0.45	0.43
	Total Fe (g/L)	0.68	0.75	0.86	2.61	3.69	6.09	9.06	10.07	12.80
	pH	1.82	1.75	1.61	1.49	1.46	1.37	1.30	1.13	1.10
PLS	Cu^{2+} (g/L)	2.61	2.42	2.14	1.83	1.48	1.41	1.23	1.52	1.17
	Total Fe (g/L)	0.42	0.72	1.13	2.83	3.99	6.95	10.06	13.00	15.62
	pH	2.55	2.49	2.14	1.79	1.65	1.53	1.39	1.30	1.19

Table 6
Dissolution of Fe, As and S

	Grade of residue (%)				Dissolution (%)			
	Cu	Fe	S	As	Cu	Fe	S	As
Heap 1	0.220	2.59	2.40	0.044	80.58	12.53	28.36	50.00
Heap 2	0.173	2.90	2.44	0.035	65.94	19.22	28.86	32.00

- Raffinate was periodically neutralized to balance acid and ferric ion using limestone powder. The result of raffinate neutralization is presented in Table 9.
- One stage iron strip from loaded organic was tested in SX unit to improve current efficiency. The results of iron strip are shown in Table 10.

After continuous effort to optimize the operation of the plant, copper cathode, copper production and operation cost were significantly improved. Chemical analysis of the copper cathode, copper production and operation cost of the plant are shown by years from 2001 to 2003 in Tables 11, 12 and 13.

7. Commercial plant

The commercial plant with a capacity of 10 000 t/a copper cathode will be commissioned by the end of 2005. Underground mining system supplies 10 000 t ore per day at an average grade of 0.45% total copper. Permanent heaps will be adopted for bioleaching. A three stage crushing plant is designed to crush ore to a size of 100% passing 15 mm. The SX unit is designed as a two-stage extraction, one-stage iron stripping and one-stage copper stripping circuit. LIX 984N is selected as the copper extractant for the Zijinshan commercial plant. The copper recovery for bio-heap leaching is expected to reach 80% in a leaching period of 200 days.

The estimated capital cost for the commercial plant is US $31.86 million.

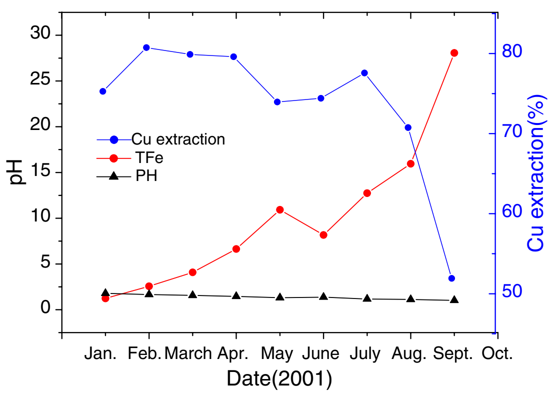

Fig. 6. Copper extraction by month.

Table 7
Typical solution analyses

	Cu (g/L)	Fe (g/L)	SiO_2 (mg/L)	Al^{3+} (mg/L)	Co (mg/L)	As (mg/L)	Mn (mg/L)
PLS	1.85	12.55	131.19	763.73	20.46	199.58	21.32
Electrolyte	39.10	2.04	47.34	109.94	108.91	5.16	4.18

Table 8
Copper recovery of the heap with 10-m lift

	Cu (%)	Height of piles (m)	Retention time (days)	Extraction (%)
Heap 3	0.505	10	200	80.72

Table 9
Neutralization of raffinate

	pH	Cu^{2+} (g/L)	Fe^{3+} (g/L)	Cu loss (%)	Fe precipitation (%)
Raffinate	1.02	0.650	28.35	8.92	90.30
Neutralized	2.16	0.592	2.75		

8. Conclusion

The pilot plant tests have demonstrated that bio-heap leaching of chalcocite ore with high pyrite content in a rainy area is viable. Based on the pilot plant tests, the first bio-heap leaching commercial plant in China will be

Table 10
Iron strip from loaded organic

O/A	Loaded organic		Striped organic		Iron stripping (%)
	Cu^{2+}	Fe^{3+}	Cu^{2+}	Fe^{3+}	
1.13	3.546	0.02	3.483	0.008	60.00
1.14	2.094	0.062	1.892	0.027	56.45
1.25	4.029	0.056	3.569	0.031	44.64
1.30	2.763	0.024	2.749	0.012	50.00
1.34	4.088	0.039	3.912	0.018	53.85

Table 11
Output of copper cathode from 2001 to 2003

	2001	2002	2003
Piled ore (tons)	48 997.26	134 794.06	338 444.29
Cu (%)	0.92	0.95	0.45
Copper cathode (tons)	185.56	650.47	839.58

Table 12
The chemistry of typical copper cathode

	Cu	Zn	S	Pb	As	Sb	Bi
Nov. 2001	99.97	0.00019	0.0016	0.0043	0.00015	0.0001	0.0001
May 2002	99.98	0.0005	<0.0005	<0.0005	0.0005	<0.0005	<0.0005
May 2002	99.98	<0.0005	0.0008	<0.0005	<0.0005	<0.0005	<0.0005

Table 13
Operation cost (US cent per pound copper)

	2001	2002	2003
Milling and crushing	18.60	18.05	30.41
Heap leaching	3.79	0.81	1.18
SX	7.44	9.60	7.60
EW	10.64	8.73	8.80
Neutralization	4.15	3.48	2.55
Labour cost	22.59	3.83	2.64
Cash cost	67.21	44.50	53.18

commissioned this year. Water balance, acid and iron balance remain challenges to the commercial plant.

Acknowledgement

The pilot plant tests were funded by Ministry of Science and Technology of P.R. China. The authors wish to thank all those who contributed to the projects.

References

[1] Ruan Renman, Copper recovery from Zijinshan chalcocite ore by flotation, Utilization of Mineral Resources, 6 (1999), 27–31.

[2] Ruan Renman, Wen Jiankang, Bacterial leaching of Zijinshan chalcocite ore with mesophile, Nonferrous Metals, 4 (2000), 159–161.

[3] Ruan Renman, Wen Jiankang, Chan Jingghe, Column leaching of Zijinshan chalcocite ore with mesophile, Copper/Nickel Hydrometallurgy Symposium, Xiamen, (2001), p. 59–64.

[4] Ruan Renman, Wen Jiankang, Wu Luangdong, Wu Jianhui, Preliminary report of pilot plant testworks on Zijinshan chalcocite ore, unpublished report, General Research Institute for Nonferrous Metals and Zijin Mining Co., Ltd. (2004).

[5] Yang Song, Yuan Guocai, Preliminary design of Zijinshan copper mine, unpublished report, Nanchang Engineering Institute on Nonferrous Metallurgy (2004).