

## AGITATION LEACHING OF SAINDAK OXIDIZED COPPER ORE USING SULPHURIC ACID

KHADIM HUSSAIN, N. SHEIKH and M. A. QAZI

PCSIR Laboratories, Lahore

(Received November 18, 1974; revised March 19, 1975)

**Abstract.** Investigation of agitation leaching of Saindak oxidized copper ore using 10–100 g/l sulphuric acid has been carried out with a view to optimize particle size, acid consumption, and liquid–solid ratio. Copper extraction up to 96% was achieved using ore of –60 mesh size, a liquid–solid ratio of 2.5/l, and the corresponding acid consumption was found to be 2.47 kg/kg Cu extracted. The particle size of –8 mesh was found much more convenient from the filtration point of view, but gave 57% recovery in 30 min, with liquid–solid ratio of 2.5/l, and an acid consumption of 2.6 kg/kg Cu extracted. Fines were separated from the crushed ore and were separately leached with the acid. An extraction of 93% was achieved using liquid–solid ratio of 1.5/l with an acid consumption of 4.2 kg/kg Cu extracted. The kinetics studies indicate, that the agitation leaching of the ore is a first order reaction.

Recently a large porphyry-type copper deposit has been discovered in 'Sulphide Valley, 3 miles southeast of Saindak Fort in Chagai District, Baluchistan.<sup>1</sup> The copper mineralization zone is confined to a 0.3–1 mile wide and 4–5 miles long strip covering an area of over 2 sq miles. The over-burden of the ore body contains oxidized copper minerals, malachite and azurite, to a depth of about 50 ft. The gangue minerals and rocks associated with the copper minerals are reported to be quartz-diorite, basalt, andesite, tuff and siltstone.<sup>2</sup>

The mineralogical composition of Saindak copper ore indicates that no acid consuming gangue minerals are present in the ore.<sup>3</sup> The leaching may, therefore, be carried out by means of sulphuric acid, which is a frequently used solvent for the leaching of oxidized copper ores.

When the copper ore is subjected to crushing for the preparation of feed for percolation leaching, some of the copper values are concentrated in the fines. Such fines, because of the particle size, do not permit the free passage of the leach solution through the interstices and thus the ore cannot be effectively leached by percolation. Such fines are, therefore, treated invariably by agitation leaching.

The Saindak ore samples as received distinctively contained two grades, as shown in Table 1. The lower grades were mixed together and designated as group I ore, and the higher grades were named as group II ore. The agitation leaching of group II ore, and the –8 mesh fractions of ores of both the groups has been carried out, using sulphuric acid as a leaching agent. The study includes the evaluation of the important parameters affecting the rate of leaching such as acid concentration, particle size, and the liquid–solid ratio.

*Description of the Ore Sample.* Trench samples of the ore, ranging in size from 1 to 3 in, reported to be collected from different areas of central oxidized zone of Saindak copper deposit, were received from the Geological Survey of Pakistan. The data represented in Table 1 indicates the location, weight and copper content of the respective samples.

TABLE 1. HEAD SAMPLES, THEIR LOCATIONS, WEIGHTS and COPPER CONTENTS.

Sample No.	Location	Wt of samples as received (kg)	Copper content (%)
1	ZS-1 and ZS-2	48.0	0.49
2	ZN-1 and ZN-2	34.0	0.32
3	Central oxidized zone	28.5	0.32
4	"	50.0	0.48
5	"	60.5	0.48
6	"	53.0	0.48
7	"	80.5	0.95
8	"	47.0	0.24
9	"	63.0	1.27
10	"	67.0	0.32

*Grouping of the Samples.* It is evident that the grade of copper varies from 0.3 to 0.5% in samples 1–6 and 10 whereas in samples 7 and 9, the amount of copper present is around 1.0% (Table 1). Based on the copper content in the ore, the ore samples from different areas were divided into two broad groups. Group I composed of the ore relatively low in copper content and included samples 1–6 and 10. The samples 7 and 9 containing comparatively higher percentages of copper were mixed together and designated as group II. The sample 8 was discarded due to its lowest copper content. Table 2 presents the chemical analyses of the composite ore samples of group II, and fines separated (–8 mesh fractions) from the samples of groups I and II ores.

*Sample Preparation for Leaching.* For agitation, leaching tests, three types of bulk samples were prepared. Firstly, group II ore was crushed in rolls and ground in a rod mill to obtain samples of –5, –8, –16, –25, –44 and –60 mesh sizes (BSS sizing screens were used throughout the study).



TABLE 2. CHEMICAL ANALYSES OF GROUP II ORE AND -8 MESH FRACTIONS OF GROUPS I and II ORES.

Chemical constituent	Group II ore	-8 mesh fraction of group I ore	-8 mesh fraction of group II ore
Copper (Cu)	1.10	0.70	1.78
Iron oxide ( $\text{Fe}_2\text{O}_3$ )	5.72	6.32	5.68
Silica ( $\text{SiO}_2$ )	78.40	78.22	77.50
Alumina ( $\text{Al}_2\text{O}_3$ )	4.25	5.65	4.26
Calcium oxide (CaO)	3.00	3.70	3.02
Magnesium oxide (MgO)	Traces	Traces	Traces
Combined sulphur (as $\text{SO}_3$ )	2.62	2.52	2.65
Loss on ignition	4.80	2.82	4.82

TABLE 3. SIZE DISTRIBUTION OF THE THREE BULK SAMPLES.

Mesh size (BSS)	First bulk sample (wt %)	Second bulk sample (wt %)	Third bulk sample (wt %)
- 8+12	25.5	12.8	13.5
- 12+16	18.0	13.2	12.0
- 16+22	13.5	11.7	10.3
- 22+44	18.0	18.9	17.8
- 44+60	25.5	7.4	7.5
- 60+85	—	6.9	7.0
- 85+100	—	3.4	2.3
- 100+150	—	5.0	6.0
- 150	—	20.1	22.8

Based upon the experimental observations of the group II ore samples (prepared as above), it was assumed that -8 mesh ore would serve as a suitable size fraction for further study. Some fines were generated during the preparation of 1 in feed (for percolation leaching) by crushing the groups I and II ores in a jaw crusher (opening 1 in). These fines were separated from the crushed ore by screening through an 8 mesh sieve and labelled as second and third types of bulk samples. The -8 mesh fractions of groups I and II so obtained weighed 7 and 13% of the total weight of the crushed ore and contained 0.7 and 1.8% copper respectively. Table 3 indicates the sizing analysis of the three bulk samples prepared as above for agitation leaching tests.

**Leaching Procedure.** The leaching tests were carried out in a Pyrex beaker 500-ml capacity.<sup>4</sup> In each test, 100 g ore of specific size fraction was treated with 250 ml sulphuric acid of known strength. The slurry was agitated with a glass stirrer having fixed speed of 1000 rev/min. In each case, 2-5 ml of the leach liquor was drawn with a pipette attached with a porous plug, after 1, 3, 5, 10 and 15 min agitation and preserved for subsequent analysis.

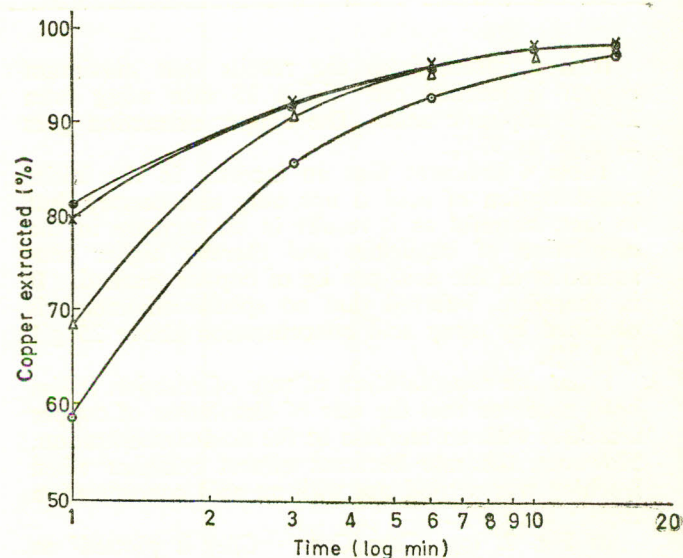


Fig. 1. Agitation leaching of Group II ore (minus 60 mesh size) using different concentrations of sulphuric acid at a liquid-solid ratio of 2.5/1 (strength of  $\text{H}_2\text{SO}_4$ : Open circle, 2.5%; triangle, 5.0%; cross, 7.5%; and closed circle, 10.0%).

The samples were analysed for copper, iron and free sulphuric acid by using standard analytical methods. All the leaching tests were carried out at room temperature (25°C).

## Results and Discussion

### Agitation Leaching of Group II Ore

**Effect of Acid Concentration.** Ore samples of -60 mesh size were arbitrarily selected to study the leachability of group II ore using various acid concentrations. The leaching was done with 1, 2.5, 5.0, 7.5 and 10% sulphuric acid and at a tentatively selected liquid-solid ratio of 2.5 : 1, for a period of 15 min and agitation speed of 1000 rev/min.

The results in Fig. 1 indicate that there is a marked difference in the initial rate of copper extraction when using acids of a strength higher than 25 g/l (2.5%). Acid strength higher than 50 g/l (5.0%) does not show a significant increase in the copper extraction.



TABLE 4. DISSOLUTION OF COPPER AND IRON AND ACID CONSUMPTION FOR GROUP II ORE (liquid—solid ratio, 2.5/1; ore size, -60 mesh; leaching time, 15 min; and wt of ore, 100 g).

Initial H <sub>2</sub> SO <sub>4</sub> concn (g/l)	Cu extd (g/l)	Fe extd (g/l)	Final H <sub>2</sub> SO <sub>4</sub> (g/l)	H <sub>2</sub> SO <sub>4</sub> used (kg/kg Cu extd)
25	4.28	0.09	14.40	2.47
50	4.28	1.45	34.80	3.54
75	4.30	1.92	57.50	4.06
100	4.34	3.78	78.00	5.07

It is apparent from the results that maximum copper is leached out within 15 min using even 25 g/l sulphuric acid. The copper extraction goes as high as 97%.

Table 4 indicates that an increase in the initial concentration of acid is not only unnecessary, but in fact, harmful as it results in an increase in the dissolution of impurities and thereby higher consumption of the acid per kg of copper leached. It is, therefore, inferred that no special advantage is obtained by using acid concentration above 25 g/l (2.5%).

From the consideration of rate of reaction it has been observed that the rate of dissolution of copper increases with an increase in the acid concentration. However, the rate becomes almost constant when leaching was carried out with an acid concentration higher than 5%.

In Fig. 2,  $\log (C_{u\infty}/C_{u\infty} - C_{ut})$  is plotted<sup>5</sup> as a function of time; where  $C_{u\infty}$  and  $C_{ut}$  are the copper concentrations at infinite time and time  $t$  respectively. The linearity of the plots reveals that the leaching is a first order reaction after 1 min. From the slope of the lines the reaction rates have been calculated to be  $5.4 \times 10^{-3}$ ,  $9.09 \times 10^{-3}$  and  $8.2 \times 10^{-3}$  mole/litre/sec respectively for 25, 50 and 75 g/l sulphuric acid, used for the leaching of -60 mesh ore.

**Effect of Particle Size.** A number of tests were conducted to find out a particle size range which could give maximum copper extraction and exhibit an efficient post leaching sedimentation. The ore was pulverized to obtain samples passing through 5, 8, 16, 25, 44 and 60 mesh sieves. Leaching tests were performed at a liquid—solid ratio of 2.5/1 using 25 g/l sulphuric acid. The leaching time was extended up to 35 min due to the observed slow leaching action on larger particle sizes. The effect of particle size on the leachability of copper with respect to time is represented in Fig. 3.

The curves reveal that per cent extraction of copper successively improves with the gradual decrease in the particle size. In case of the ore samples of -60 mesh size, fairly good extraction is noticed even at the early stages of leaching. An average

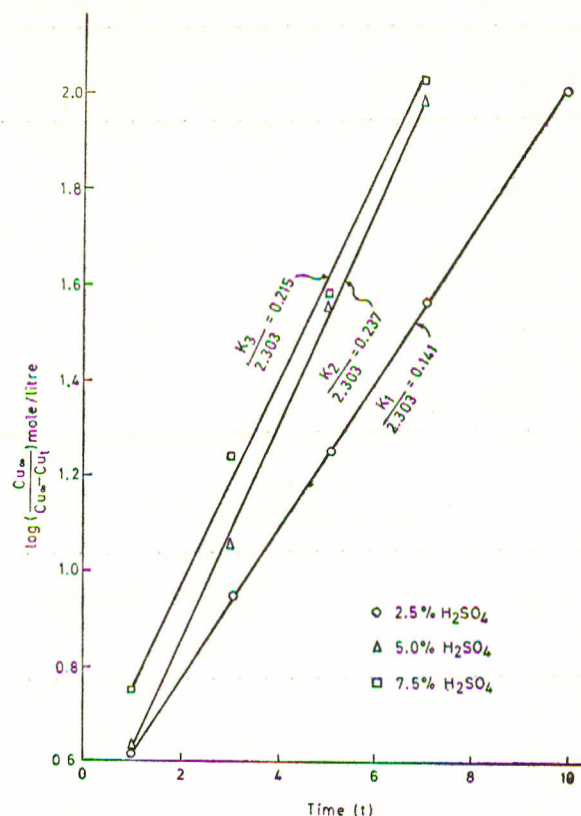


Fig. 2.  $\log (C_{u\infty}/C_{u\infty} - C_{ut})$  plotted against time.

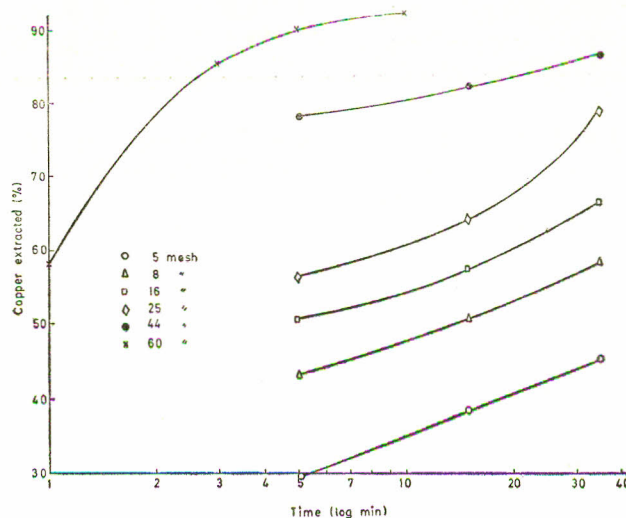


Fig. 3. Effect of particle size on the extraction of copper using 2.5% H<sub>2</sub>SO<sub>4</sub> (wt).

increase of 7.5% in the copper extraction is observed if leaching is extended from 15 to 30 min. Leaching for further time period, although yields some more copper in solution, but the extraction rates become very slow. The results of 20 min leaching study



indicating acid consumption for various size fractions of the ore, copper extraction and iron dissolution are presented in Table 5.

It has also been observed that leaching the ore finer than 8 mesh size makes the sedimentation and filtration of the final slurry difficult. In leaching of -8 mesh ore about 51% copper is extracted in 15 min, which increases to 57% on extending the extraction to 30 min. More leaching time, however, was required if further extraction of copper was desired. It was concluded that -8 mesh size ore was the proper grind size for easy extraction of copper from the ore.

*Effect of Liquid-Solid Ratio.* A series of experiments were performed using -8 mesh ore and 25 g/l sulphuric acid to determine the effect of liquid-solid ratio by weight, or pulp density on the extraction of copper. The liquid-solid ratio was varied from 1/1 to 3/1. The leaching was done for 15 min, and

the copper was determined at the end of each run. The results of the tests are: 1.0/1, 52.4%; 1.5/1, 52.6%; 2.0/1, 57.1%; 2.5/1, 57.2%; and 3.0/1, 58.4%.

The results indicate that increasing the liquid-solid ratio above 1/1 causes only a slight improvement in the copper extraction. The explanation for such a behaviour may be that the particles at the beginning are leached superficially, the concentrated solution enveloping the particle is displaced by the fresh leachant of lower copper content under the strong agitation conditions. After the surface of the particle is leached, a concentration gradient is established at the surface and the interior of the particle, and the leaching rate becomes diffusion-controlled. The increase in liquid-solid ratio, therefore, will have no marked effect on the leaching rate of the ore as long as the particle is constantly submerged in the acidic solution.

From the leaching and settling tests it was found that a liquid-solid ratio of 1.5/1 offered a reasonable operating condition for -8 mesh ore.

#### *Agitation Leaching of -8 Mesh Fractions of Groups I and II Ores*

It is inferred from the results obtained on the agitation leaching of fine ores, as discussed earlier, that -8 mesh size ore yielded reasonably high extraction of copper when leached with 25-50 g/l sulphuric acid. It was decided that the fines passing 8 mesh should be separated from coarsely crushed ores, for agitation leaching. These fractions made 7 and 13% of the groups I and II ores, and contained 0.70 and 1.78% copper, respectively. The agitation leaching tests were carried out taking 100 g samples, using 25 and 50 g/l sulphuric acid, and a liquid-solid ratio of 1.5/1. The results of the leaching tests indicating copper extraction, iron dissolution and, acid consumption are recorded in Table 6.

TABLE 5. EFFECT OF PARTICLE SIZE ON THE LEACHING OF COPPER ORE (liquid-solid ratio: 2.5/1; leach solution containing (H<sub>2</sub>SO<sub>4</sub>) 25 g/l; and leach time, 20 min).

Particle size (passing mesh)	Cu extd (g/l)	Fe extd (g/l)	Final H <sub>2</sub> SO <sub>4</sub> (g/l)	H <sub>2</sub> SO <sub>4</sub> used (kg/kg Cu extd)
5	1.80	0.14	20.30	2.61
8	2.35	0.17	18.52	2.76
16	2.64	0.17	17.33	2.91
25	2.90	0.18	15.60	3.24
44	3.64	0.21	14.41	2.91
60	4.32	0.21	12.45	2.91

TABLE 6. AGITATION LEACHING OF -8 MESH FRACTIONS OF GROUPS I and II ORES (liquid-solid ratio, 1.5/1; wt of ore for each test, 100 g).

-8 mesh fraction of	Time (min)	Initial			Final H <sub>2</sub> SO <sub>4</sub> (g/l)	H <sub>2</sub> SO <sub>4</sub> used (kg/kg Cu extd)
		H <sub>2</sub> SO <sub>4</sub> (g/l)	Cu extd (g/l)	Fe extd (g/l)		
Group I	20	25	2.26	0.14	16.95	3.56
	50	25	2.29	0.36	16.35	3.77
	20	50	2.38	0.31	40.02	4.19
	50	50	2.50	0.67	38.20	4.80
Group II	20	25	4.86	0.11	12.58	2.55
	50	25	4.90	0.23	11.32	2.70
	20	50	6.56	0.19	28.21	3.32
	50	50	6.81	0.42	25.20	3.64



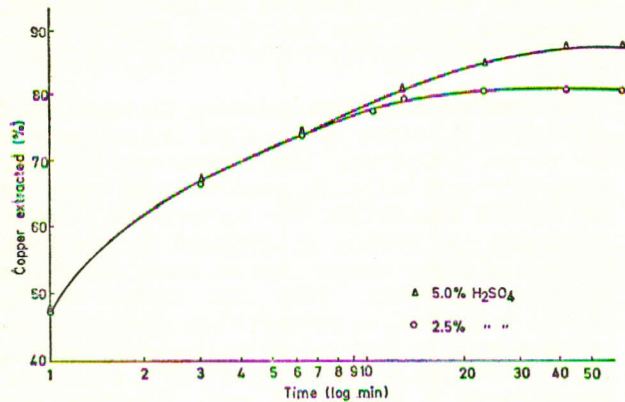


Fig. 4. Agitation leaching of —8 mesh size fraction of group I ore using 2.5 and 5.0 (wt) per cent  $H_2SO_4$  at liquid-solid ratio of 1.5/1.

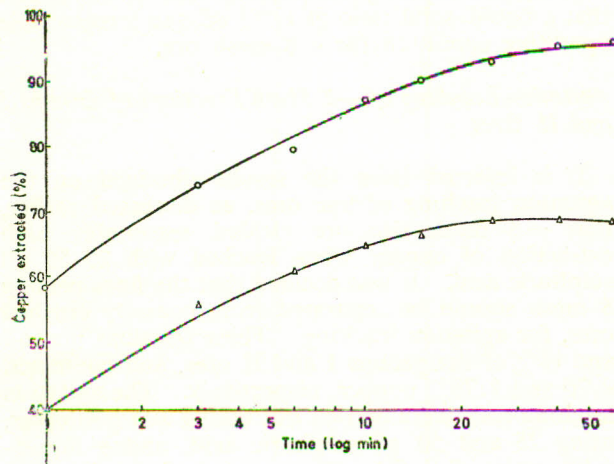


Fig. 5. Agitation leaching of —8 mesh size fraction of group II ore using 2.5 and 5.0 (wt) per cent  $H_2SO_4$  at a liquid-solid ratio of 1.5/1 (strength of  $H_2SO_4$ : triangle, 2.5%; and open circle 5.0%).

In the leaching of —8 fraction of group I ore, it is noticed that the initial leaching rate is same for 25 and 50 g/l sulphuric acid. After 15 min of leaching there was only a small improvement in the extraction of copper when using 50 g/l acid. In the case of —8 mesh fraction of group II ore, on the other hand, the difference in the initial leaching rate was quite significant. The copper extraction of about 68% was obtained in 20 min on leaching with 25 g/l sulphuric acid, whereas the extraction was found to be about 93% within the same time when 50 g/l sulphuric acid was used. Keeping in view the low iron-content and the porous nature of the —8 mesh fractions of the ore, maximum extraction in minimum time can be achieved with 50 g/l sulphuric acid.

### Conclusion

The agitation leaching of various sizes of groups

II ore (1.1% Cu) for 15 min using different concentrations of sulphuric acid revealed that as much as 96% copper extraction could be achieved. Such a high extraction was possible by leaching —60 mesh ore samples with acid concentration of 25 g/l, and using a liquid-solid ratio of 2.5/1, by weight. The acid consumption for group II ore was found to be 2.47 kg/kg copper extracted. The leaching of such a fine ore size, however, caused not only serious problems of sedimentation and filtration, but also may be a costly operation due to high cost of fine grinding.

In the leaching tests on group II ore of different sizes, it has also been found that a particle size of —8 mesh when leached with 25 g/l (2.5%) sulphuric acid, although extracted about 57% copper in 30 min at liquid-solid ratio of 2.5/1, the settling rate of the slurry was found to be ideal and the filtration was much more convenient. The acid consumption was found to be 2.6 kg/kg copper extracted. This acid consumption was slightly higher than that in the case of —80 mesh size ore. The higher recoveries of copper with 25 g/l acid, however, were possible when the leaching time was extended.

The liquid-solid ratio above 1/1 did not have significant effect on copper extraction and a liquid-solid ratio of 1.5/1 was found to yield optimum extraction and fast settling pulp.

In the leaching of fines (—8 mesh size fractions) of group I (0.70% Cu) and group II (1.78% Cu) ores constituting 7 and 13% of the crushed ores respectively, it was found that with 50 g/l sulphuric acid the corresponding copper extractions were 85 and 93% respectively in 20 min by maintaining a liquid-solid ratio of 1.5/1. The acid consumptions for the respective ore fines were 4.19 and 3.32 kg/kg copper extracted. The increased acid concentration, if used for leaching such fine fractions, dissolved lesser amount of iron in the leach liquor, but comparatively higher amount of iron was dissolved from the ore samples when acid concentration exceeded 25 g/l.

### References

1. W.J. Ahmad, S. N. Khan and R.G. Schmit, U.S. Geological Survey, Proof Paper 716-A (1972).
2. S.N. Khan, Report No. 1 (Geological Survey of Pakistan, 1972).
3. M.A. Qazi and N. Sheikh, Sulphuric Acid Leaching of Saindak Oxidized Copper Ore, Investigation Report (unpublished, PCSIR Laboratories, Lahore, 1974).
4. J.T. Woodcock, Acid Leaching of Oxidized Copper Ore from Mount Gunson, Ore Dressing Investigations Report No. 663 (CSIRO, Melbourne, 1966).
5. B. Stevens, *Chemical Kinetics* (Chapman and Hall, London, 1970) p. 19.