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Diagnostic metallurgy of porphyry copper – gold deposits in the Pan-Pacific

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Abstract: The variable flotation response ores from different deposits results basically from mineralogical association and their differences. Development of new techniques for analyzing the metallurgical performance of flotation and other concentration processes is demanded even in the treatment of rather simple ores such as porphyry ores. Diagnostic metallurgical analysis can be used to quantify the most possible recovery processes. Several porphyry copper / gold ores around the world were used to examine the responses in flotation, gravity separation and cyanidation in order to define the linkage between the recovery processes for both copper and old values.

Laboratory batch flotation, gravity separation and cyanidation tests were carried out on these samples. All results were used to correlate the relative recovery of copper and gold, and to predict the highest possible metal recovery in the system. The metallurgical predictions were made according to the flotation conditions used and gravity separation. The results of various concentration processes on each porphyry ore samples are presented and discussed.

All seven samples have shown significantly different gold / copper metallurgy. The grade/recovery relationships of gold and copper in the laboratory batch tests for the best results and the plants are given in the Figures below. The results of laboratory tests show that the copper recoveries converged to about 90%, but the gold recoveries were spread over 55 – 80%, except the K S ore. Series of standard cyanidation tests on the flotation concentrate samples and gravity separation using Knelson Separator on heads ores were carried out to cross-link the metallurgy and mineralogy of gold in the porphyry ores.

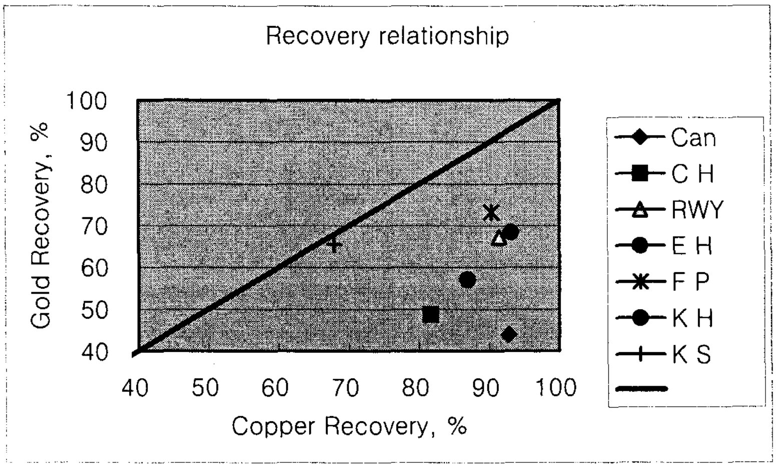

Figure. Recovery relationship between copper and gold.

Conclusions

(1). The basic optimization tests have shown that a good spread of Cu / Au grade and recovery has been obtained from seven different Cu/Au porphyry ore samples.
(2). The laboratory batch flotation test can be used as a simple tool in predicting the grade / recovery relationships.
(3). Flotation, cyanidation of the flotation products and gravity separation provided very close the links between the mineralogy and flotation recoverable gold, and gold deportment in the process.
(4). The application of the findings of the present study in the evaluation of new deposits is highly recommended.

Methodology

Series of statistically designed flotation experiments for each seven samples have been carried out. The three major variables examined were fineness of grind, collector dosage and pulp pH.

All samples were crushed to pass 10 mesh and splitted in to 2-Kg tests lots. For flotation tests, samples were ground in a laboratory rod mill at 65% solids for a specific time. Lime was added in the mill when the pulp pH was subjected to vary from its natural pH. The ground pulp was diluted to about 40% solids at the same pH and conditioned with collectors for 5-min. The rougher flotation was then carried out with MIBC added in stages. 4-5 incremental concentrates were retained and analyzed for copper and gold. Three major variables, namely, the mesh of grinding, pulp pH and the collector dosage were examined to define the flotation responses. Standard cyanidation leaching tests using the flotation concentrates have been performed to obtain information on the amount of readily leachable gold and copper content. The results of cyanidation tests provided indirect information with regard to the gold and copper mineralogy. Knelson Separator was adopted for the separation of the ground ore to define the amount of gravity recoverable gold. The assays of the mill feed samples and the target grind are given in Table 1.

Table 1. Heads assays and the target grind of the seven porphyry copper res.

Sample	% Cu	g/t Au	Target grind
K H	0.22	0.79	60% -200M
K S	0.20	0.95	60% -200M
C H	0.13	1.01	70% -150M
RWY	0.89	1.70	70% -150M
E H	1.13	0.63	80% -100M
Can	0.89	0.29	90% -100M
F P	1.25	1.62	70% -100M

Results

A. FLOTATION

A.1 K H Ore

The natural pH was about 8. Raising the pH above 10 resulted in a very thick pulp. The pulp became very viscous around pH 10. This is most likely due to the presence of highly expendable clays in the ore. The results of flotation of copper and gold are given in Figure 1, where selectivity of Cu/Au.

All three factors are significant in affecting copper and gold flotation. The best results were obtained with the finer grinding, high collector dosage (or strong) and natural pH. Recoveries of 90% copper and 65% gold were reached at concentrate grades of about 4% Cu and 11g/t Au.Finer grinding and higher collector dosage increased the gold and copper recoveries and grades. Over 90% copper recoveries were reached, but the gold recoveries barely reached to about 65%, indicating the maximum gold recovery by flotation is about 70%. It can e deducted from these results that the rest of the gold is present as un-liberated, or un-floatable phases. The statistically analyzed results have shown that :

(i) gold recovery is increased with increasing fineness of grinding, and high collector at high pulp pH raised the gold recovery, but no significant effect on the gold grade.
(ii) copper recovery and grade were increased with increasing grinding,
(iii) increasing collector dosage and pH increased the recovery, but not the grade.

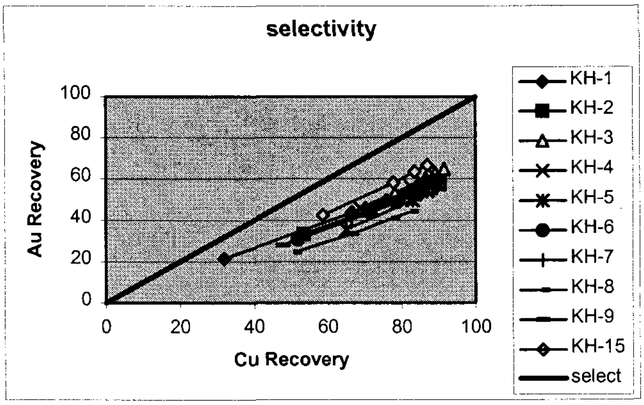

Figure 1. Recovery relationship between copper and gold, K H ore.

A.2 K S Ore

The natural pH was about 8. Raising the pH to above 9.5 resulted in a very thick pulp. The pulp became very viscous beyond the natural pH due to the presence of highly expendable clays and very advanced oxidation stage. Therefore, the pulp pH was excluded as a test variable. It was found that extremely high xanthate addition was required to initiate flotation. The requirement of collector to form a reasonable froth layer was solely depended on the amount of collector added. However, it is well known in the practice of porphyry operation when there is a high slush of clay and oxidized material is on, a high collector and forther addition is unavoidable. The results of flotation are given in Figure 2, where the selectivity of Cu/Au.

The results showed that the finer grinding and high collector dosage resulted in a very fast flotation as well higher concentrate grades. Unlike to the K H ore, the maximum achieved recoveries of gold and copper were about 70%. Practically the floatability of gold and copper were the same.

The statistical analysis of the flotation responses revealed that the gold grade was not significantly affected by the fineness of grind, which indicates that the liberation of floatable gold is already achieved at about 58% -200mesh. But low gold grade was resulted with low collector dosage. Obviously low collector and coarse grinding gave poor gold recovery. Copper flotation followed exactly same pattern as that of gold.

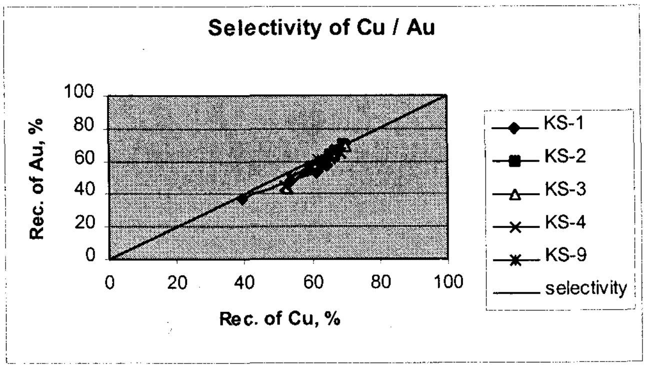

Figure 2. Recovery relationship between copper and gold, K S ore.

A.3 Can Ore

The natural pH was about 7.8. Unlike to KH and KS ores, raising the pH to above 9.5 did not change the physical nature of the pulp. Therefore, the collector dosage instead of pH was excluded from the testing variables. The fineness of grinding was varied from 54% -200 mesh to 68% -200 mesh, while fixed amount of collector dosage was used through out the tests.

The results of flotation are given in Figure 3, where selectivity of Cu/Au and flotation kinetics are plotted. The results as shown the copper recoveries of the Can ore reached to 90-95%, but gold recoveries reached barely 40-50%. In other words, the fineness of grinding from 48% -270mesh to 60% -270mesh did not change the copper recovery significantly, however, even with finer grind and high pH flotation made the gold recovery worse. Finer grind and natural pH flotation is the best conditions for gold flotation. On the other hand, copper flotation was better at higher pH, giving higher concentrate grade.

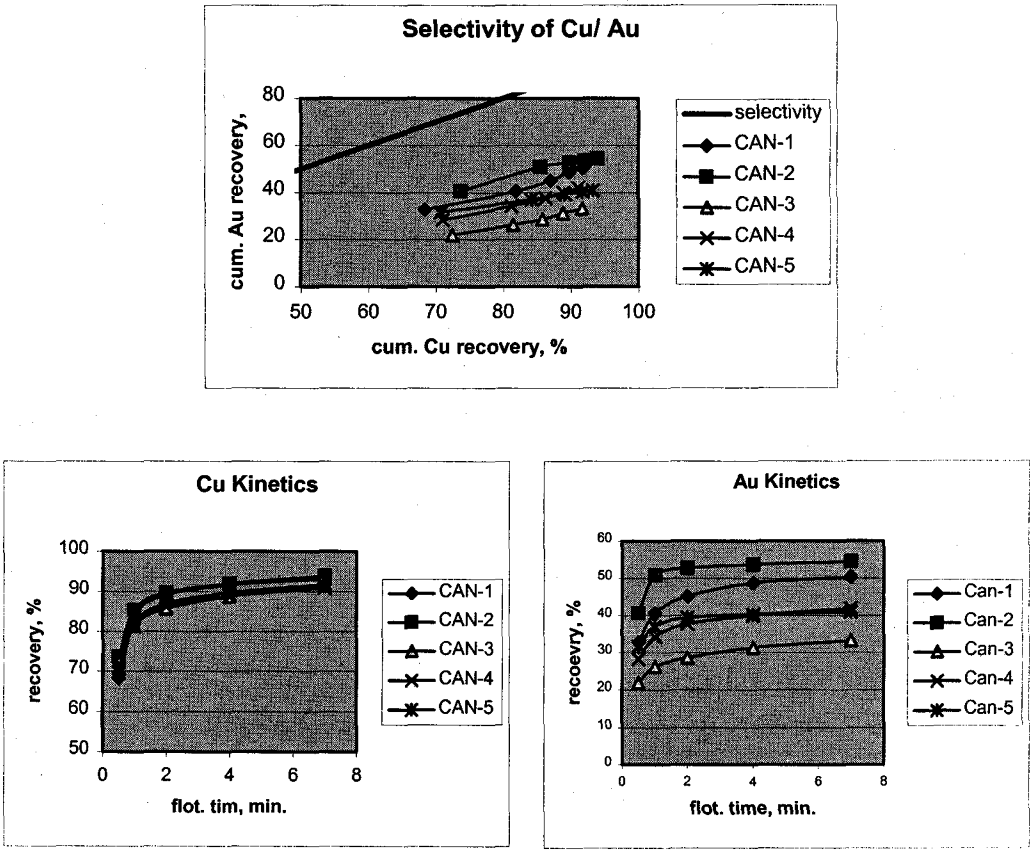

Figure 3. Recovery relationship between copper and gold, and flotation kinetics of Can ore.

A.4 C H Ore

The plant target grinding is 70% -150 mesh. The natural pH was about 8.2. The fineness of grinding was varied between from 60% 150 mesh to 70% -150 mesh (47% -200 mesh to 54% -200 mesh). Collector was varied between potassium ethyl xanthate and sodium isopropyl xanthate at a dosage of 15g/t. These two xanthates were selected since ethyl xanthate is the lowest xanthate while isopropyl xanthate is relatively strong one.

The results of flotation are given in Figure 4, where selectivity of Cu/Au is plotted. The copper recoveries of the C H ore reached to about 85%, but gold recoveries reached barely 60%. Obviously, the higher collector and finer grind resulted in a better gold and copper metallurgy. Increased pulp pH increased both copper and gold recoveries as well as the concentrate grades.

The results of these statistical analyses have shown that increasing pH and collector dosage increased the gold recovery in the concentrate, while the fineness of grinding decreased the recovery. However, the gold grade was significantly increased with increasing pH, collector dosage and grinding. The copper recovery, on the other hand, was increased with increasing grind and collector only when the pulp pH was in the low range. The copper grade was less affected by these three factors at a lesser degree, but somewhat better concentrate grade was realized at higher pH, and collector dosage.

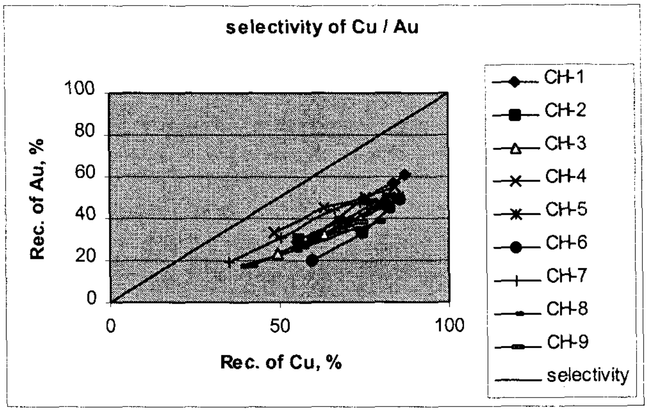

Figure 4. Recovery relationship between copper and gold of C H ore.

A.5 RWY Ore

The plant target grind for RWY ore is also 70% -150 mesh. The mesh of grind was varied between 53% -150 mesh and 72% -150 mesh. The natural pH was about 8.5, and varied between 6.5 and 8.5. Collector used was either the potassium ethyl xanthate or sodium isopropyl xanthate at a dosage of 10g/t. These two xanthates were selected since ethyl xanthate is the lowest xanthate, while the isopropyl xanthate is relatively strong one

The flotation responses are plotted in Figure 5 for the selectivity of copper and gold. As can be seen, the copper recoveries reached over 90%. And the recoveries spread widely between 88-95% for copper and 55-75% for gold. The copper recovery was significantly affected by the fineness of grinding and pH. The finer grinding and natural pH gave better recovery, while lowering the pH to 6.5 reduced the recovery. As expected the coarse grind lowered the recovery. Obviously stronger collector (SIPX instead of KEX) gave better metallurgy.

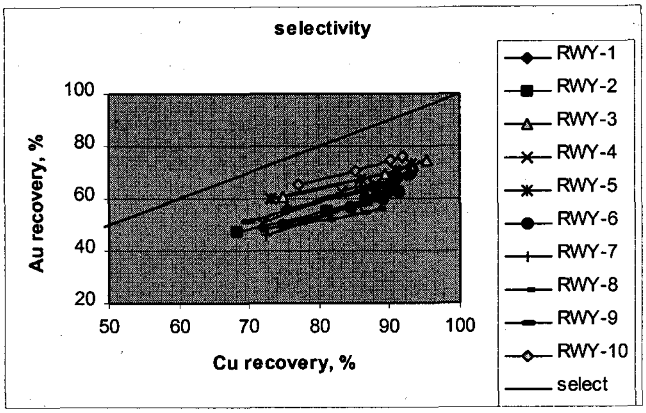

Figure 5. Recovery relationship between copper and gold of RWY ore.

A.6 E H Ore

The plant target grind for Ernest Henry ore is 80% -100 mesh. The mesh of grind was varied between 65% and 75% -150 mesh. The natural pH was about 8.5, and varied between 8.5 and 10.5 (plant pH). Collector used was sodium isobutyl xanthate at dosages of 5 - 20g/t.

The flotation responses are plotted in Figure 6 for the selectivity of copper and gold. As can be seen, the copper recoveries reached over 95%. The recoveries of gold are about 25% units smaller than that of copper. This is an indirect indication that about 25% of the gold would not be associated with copper. Although the data are not plotted here, however, the recoveries of gold and copper were not significantly affected by any of the factors, since the amount of highly floatable gold in the feed is almost remained to about 70%. However, high collector addition, finer grinding and low pH resulted in a better concentrate grade of gold as a whole. The ore responded very consistently. Also the ranges of factors examined gave very narrow fluctuation of metal recoveries and concentrate grades. Generally the flotation kinetics of copper were very fast reaching over 95% copper recovery, but the kinetics of gold is somewhat slower reaching to the ultimate recovery of about 70%. The results clearly indicate that this ore responded very optimally within the range investigated.

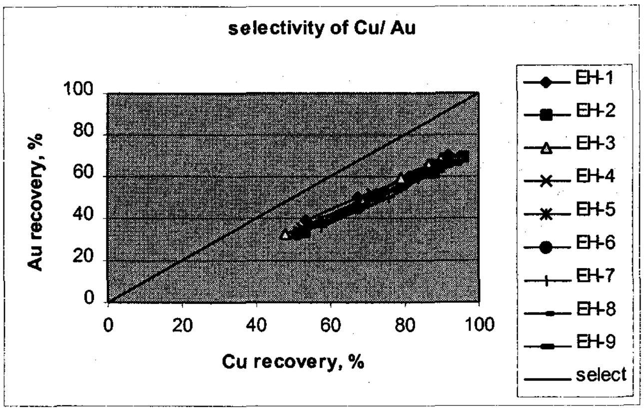

Figure 6. Recovery relationship between copper and gold of E H ore.

A.7 F P Ore

The plant target grind for F P ore is 70% -100 mesh. The mesh of grind was varied between 65% and 80% -100 mesh. The natural pH was about 7.5, and varied between 7.5 and 10.5 (plant pH). Collectors used were sodium isobutyl xanthate and dithiophosphate at dosages of 5 - 20g/t for both. These two collectors were used simultaneously as a set. The flotation was generally faster than all other ores samples tested.

The flotation responses are plotted in Figure 7 for the selectivity of copper and gold. The copper recoveries reached between 83 - 90%, while the gold recoveries ranged between 63 to 80%, suggesting that the gold flotation is highly dependable on the conditions given, and about 10% units lower than the recovery of copper. The gold recovery and grade were slightly higher with increased collector dosage. Low collector gave high grade concentrates in the early stages of flotation, but low final recovery, especially for gold. Similarly, copper flotation was low with low collector dosage. The recoveries of gold and copper were not significantly affected by any of the factors, since the amount of highly floatable gold in the feed is almost remained to about 70%. The highest copper and gold recoveries were obtained with higher collector. However, the pH and fineness of grinding had relatively small effect. The ore responded very consistently with the given conditions. Also the ranges of factors examined gave very significant to the fluctuation of metal recoveries and concentrate grades.

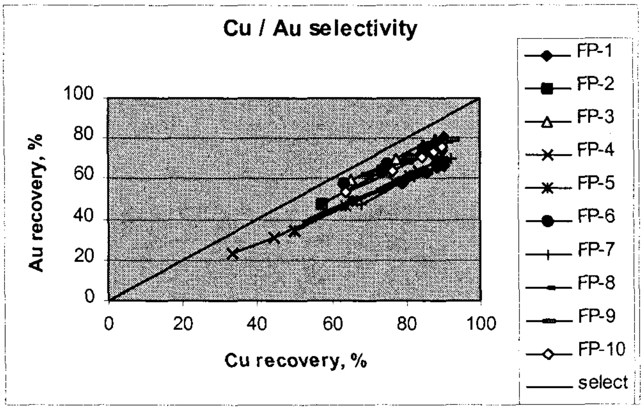

Figure 7. Recovery relationship between copper and gold of F P ore.

B. Gravity Separation

Gravity concentration using Knelson Concentrator was carried out to define the amount of gravity recoverable gold in each ore samples. The samples were ground to obtain about 80% minus 200 mesh. The feed and all products from each test were sized and analyzed, which gave the recovery of gold in each size fractions. The results in Table 2 are the re-composited data for whole ore samples. The gold recovery is strictly depended on the mineralogy, association and mode of occurrence.

Table 2. Comparison of Gold recovery in Gravity and Flotation unit operation.

Ore	Gravity Rec. %	Flotation Rec. %		Wt %	recommended process
	Gold	Gold	Copper	-200 mesh	in the grinding circuit
Can	34	53	95	83	flash flot
C H	68	60	87	85	gravity
RWY	65	75	90	78	gravity
E H	23	68	93	81	flash flot
F P	52	83	90	83	flash flot
K H	37	65	90	80	flash flot or gravity
K S	24	70	70	81	flash flot or gravity

C. Cyanidation Leaching

Following is the summary of the cyanidation tests carried out using rougher concentrates produced from the seven samples we have to date.

A 4-liter bottle rolling method at 30% solids and pH >11 was used. The initial NaCN concentration was fixed at 10-kg/t. Two series of tests for each sample was performed, namely, (i) kinetic tests and (ii) single ultimate leaching tests. In the kinetic tests, the pH and NaCN concentration were checked and adjusted at 1, 2, 4, 8, 16, 24, 36, 48 and 72-hr. The second batch tests were done with one time addition of lime and NaCN, and leached for 72-hr without interruption. Material balance and NaCN consumptions were calculated from the analytical results.

The assays of heads and cyanidation tailings obtained from the kinetic and batch tests along with the NaCN consumptions in those tests are given in Table 3 and Figures 8 to 10.

Table 3. Results of Cyanidation tests.

Samples	Heads		Cyanidation Rejects		% Leached	
	Au, g/t	Cu, %	Au, g/t	Cu, %	Au	Cu
K H	9.36	3.37	1.37	3.06	83.9	10.1
K S	15.19	2.76	6.41	0.31	54.0	88.4
RWY	34.08	20.43	20.57	17.64	12.2	33.5
C H	17.62	3.70	1.23	3.33	90.6	8.7
F P	25.17	14.58	9.67	12.31	47.8	16.2
E H	5.21	8.76	1.44	6.74	64.4	22.7
Can	3.77	12.13	0.27	11.58	87.3	2.5

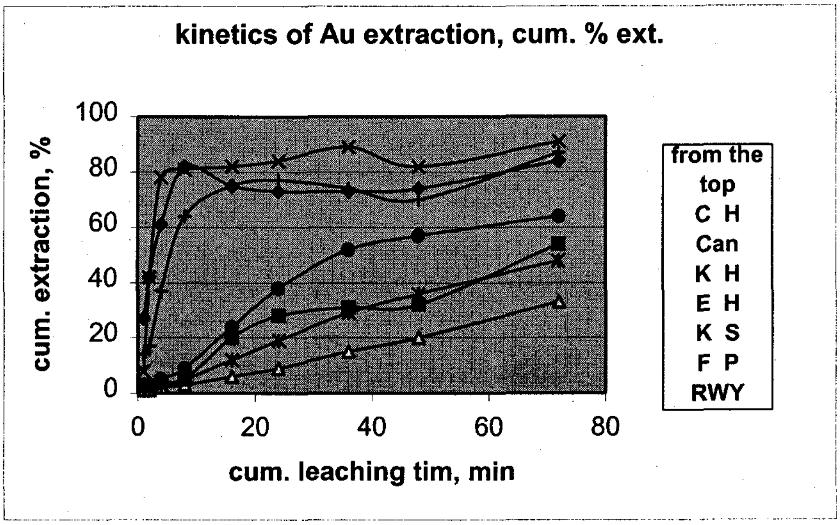

Figure 8. Kinetics of Gold Leaching with NaCN.

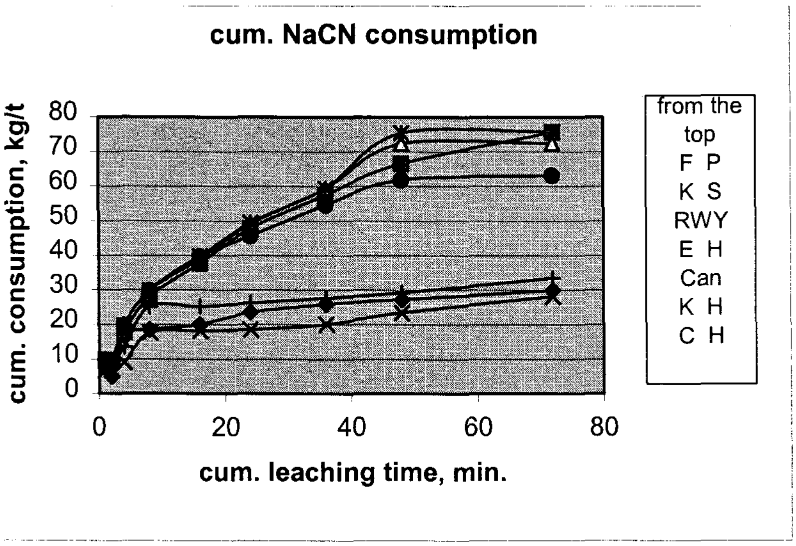

Figure 9. CN consumption as a function of leaching time.

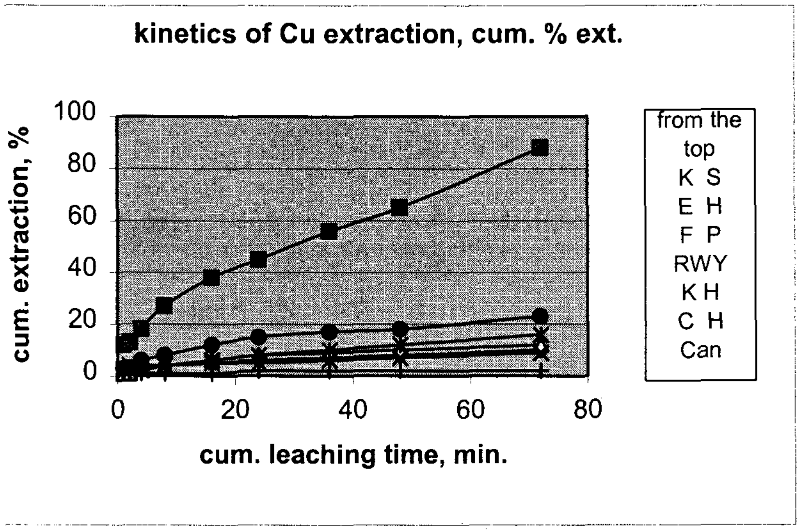

Figure 10. Kinetics of copper leaching with NaCN.