SOLUTION RATE TECHNIQUES FOR COLUMN COPPER ORE LEACHING TESTING

By

Fernando Zeballos, Julio Ayquipa,

Compañía de Minas Buenaventura S.A.A., Peru

Presenter and Corresponding Author

Fernando Zeballos
fernando.zeballos@buenaventura.pe

ABSTRACT

To run a laboratory column leaching testwork of a copper ore, the most recommendable method would be to use columns with similar or equal height of operating or designed heap lift. The main reason why it is always not possible is because full height columns demand more ore and during the project study stages it could be a restriction because the representative samples come from drill cores mainly, which are used to other project purposes also.

In the other hand, the most common solution rate used for columns leaching testing, independently of a column height, is a single rate equal to solution rate considered for industrial heap operation. When applied a full and unique solution rate for all columns size without considering the mass of ore loaded in each column, then final kinetic results will be different, hence, will be needed to use equivalence factors to standardize and analyse the testwork results, and finally use the data for heap design.

With the necessity to start a variability column leaching testwork using samples by mine bench height to support the FS of Trapiche project, in Buenaventura was run a laboratory test with three different column heights (1 m, 3 m and 6 m), using the same composite crushed and agglomerated copper ore and the same leaching conditions, but equivalent irrigation solution rates. Solution rates were based on full scale eight meters lift height (around 5 L/m^2-h) and reduced proportionally in function of ore mass loaded to each column. Ore weight is proportional to each column height. All leaching columns test has the same diameter (six inches) and were operated at 25 °C.

Considering a leaching cycle of 184 days, it was obtained an average copper extraction of 72% and similar kinetic curves for all three leaching columns. This indicate that the application of reduced *Irrigation Rate* or equivalent solution rate technique could be applied to short leaching columns and the copper extraction behaviour will be the same as if full-size columns had been used. This technique is being applied to the Trapiche project variability metallurgical leaching campaign (105 columns) with one meter columns height, so it is aligned with the little availability of core drilling samples. Variability metallurgical testwork results will be used to develop the copper extraction and acid consumption geometallurgical project models.

Keywords: column leaching, solution rate, leaching kinetics, copper leaching

INTRODUCTION

The Trapiche project is located in the Apurimac region, Peru. It is a mainly secondary copper ore hydrometallurgical project which currently is in a Feasibility Study phase. In the last years it was performed several metallurgical column leaching tests in a laboratory located in Lima city (around 300 masl), but to has a better approach to environment *in situ* conditions (4,650 masl) it was constructed a metallurgical laboratory on site, where were developed the last column leaching tests and it is performing the metallurgical variability tests campaign to support the Feasibility Study. All tests were carried out using sample composites, but for the variability metallurgical testwork it is using individual samples corresponding to a height bench that come from half diamond drill cores.

Copper extraction, acid consumption and leaching cycle are very key parameters in a copper hydrometallurgical project due to impact that have in CAPEX (initial pad), OPEX (acid consumption) and revenue (recovery), so to generate this data from representative samples from drill hole cores that allows populating the block model and finally to obtain a reasonable geometallurgical model is necessary to try a laboratory procedure that proves to be robust, reproducible and easy to scale-up to different columns or industrial lift heap. As it is known, the amount of sample from diamond drill cores is not abundant enough to carry out tests with large and/or full-size columns, the exception could be to run some column tests to study hydrodynamic of solution percolation, pH ore temperature profiles, and geotechnical parameters where composite samples can be used.

Before initiate the metallurgical variability campaign and in parallel to the parameters optimization testwork it was performed three tests using different column heights to know the copper extraction kinetics during all leaching cycle using solution rates adjusted regarding each column heigh and based on a design industrial lift of 8 m and *Irrigation Rate* of 5.0 L/h-m^2. The ore used in this test was a single composite formed with sections from drill cores of Trapiche project and performed on site project metallurgical laboratory.

Testwork conditions and results are described hereinafter in this paper. It is important to highlight that copper extraction curves were very similar for each column independent of column height (1m, 3m and 6m). It was not shown the same behaviour in the case of gangue acid consumption and related parameters, it could be due to the air injection flow, which was supplied as an unique value for each column despite of its heigh.

MATERIAL AND LABORATORY TESTS PROCEDURE

Materials Used for the Tests

Column leaching tests were performed in the facility constructed on site to carry out the project variability metallurgical testwork campaign to support the Trapiche Feasibility project stage. These tests are part of metallurgical leaching parameters optimization program developed previously to initiate the metallurgical variability test program.

These tests were performed using a general composite sample of Mixed ore as was classified in the project due to medium content of copper soluble in acid and sodium cyanide based on sequential copper chemical assay.

Composite sample chemical assay of total copper and sequential copper (also known as diagnostic leaching) are presented in Table 1 to follow:

Table 1. Copper Ore Chemical Assay

Copper assay	CuT	CuS	CuCN	CuR
Content, %	0.483	0.224	0.174	0.085

The sequential copper assay reports the copper soluble in a solution of sulphuric acid (CuS), copper soluble in a solution of sodium cyanide (CuCN) and the non-soluble copper in these solutions is considered as residual copper (CuR). The total copper content in the sample (CuT) is assayed separately.

Sequential copper assay could be reported in percentage also, as it is shown in Table 2 where is included the Leachability Index (LI) which is intended as the theoretical copper leachable (copper oxides and secondary copper sulphides) by a conventional leaching operation.

Table 2. Copper Diagnostic Leaching and the Leachability Index

Parameter	LI	CuS	CuCN	CuR
Content, %	82.4	46.4	36.0	17.6

In the other hand, as a reference the complete chemical assay of composite head sample by Atomic Absorption (AA) and Inductively Coupled Plasma (ICP) is shown in Table 3.

Table 3. Composite Sample Chemical Assay

Element	Unit	Value
AA Assay		
Cu	%	0.483
Fe	%	3.244
ICP Assay		
Al	%	5.88
Ca	%	0.34
K	+%	3.78
Mg	%	0.38
Mn	%	0.02
Na	%	0.90
S	%	2.35
Ti	%	0.03
Zn	%	0.02
Ag	ppm	3.15
As	ppm	379
Ba	ppm	757
Be	ppm	1
Bi	ppm	<5
Cd	ppm	<2
Co	ppm	22
Ni	ppm	34
P	ppm	109.5
Sb	ppm	9
Sc	ppm	6
Sn	ppm	5
Sr	ppm	169
V	ppm	95
W	ppm	<1
Y	ppm	8
Zr	ppm	4

The composite was prepared using different samples collected from half diamond drilling cores and crushed to reach a P_{80} of ½ inch as can be seen in the particle size distribution (PSD) shown in Figure 1(a). In figure 1(b) is shown the distribution of sequential copper assay, total iron assay and retained ore weight by mesh also.

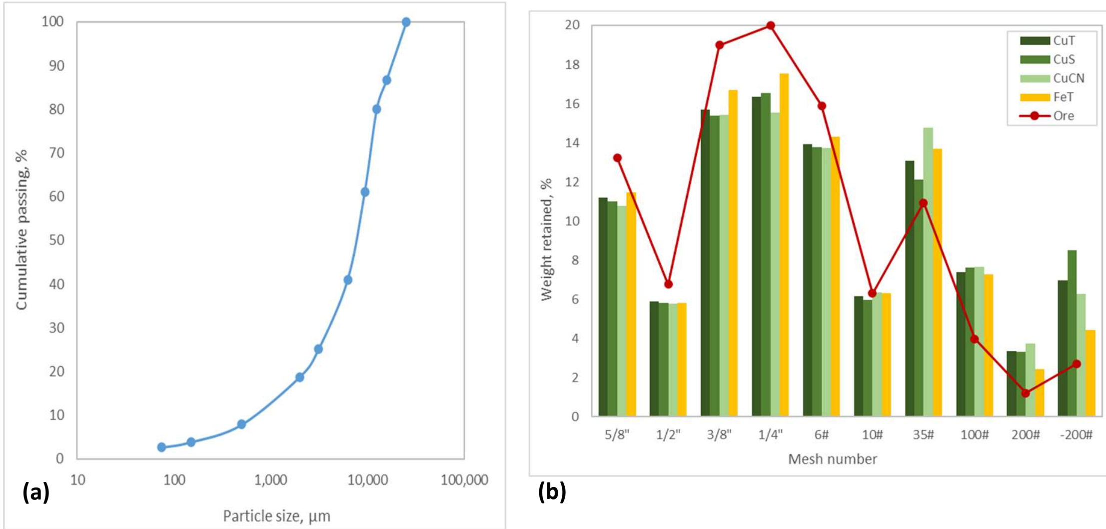

Figure 1. PSD, Copper, and Iron Distribution by Mesh Size of Sample Used in Tests

Columns used for this test has three heights: 6 m, 3 m and 1m. These PVC columns has a diameter of 6 inches, and it were isolated using fiberglass and a heat tracing system to maintain the temperature columns at 25 °C. Figure 2(a) shows the metallurgical laboratory facility on site and current columns distribution in Figure 2(b).

Figure 2. Metallurgical Laboratory at Site and Test Columns Distribution

Laboratory Procedure

The composite for these tests was divided in three samples to treat separately each sample and load each one in different heigh columns. Characteristics of the tests are described in Table 4.

Table 4. Characteristics of Each Column Test

Characteristic	Units	Column – 6 m	Column – 3 m	Column – 1 m
Ore dry weight	kg	150.1	77.2	26.2
Ore moisture	%	0.62	0.62	0.62
Agglomerate moisture	%	5.8	6.0	6.2
Curing time	days	3	3	3
Leaching cycle	days	184	184	184
Acid for curing	kg/t	5.3	5.3	5.3
Irrigation rate	L/h-m^2	3.8	1.9	0.6
Solution/ore rate (at 184 days)	m^3/t	2.0	1.9	1.9

As can be seem in Table 4, the key parameter for this test is the *Solution/Ore Rate*. It should be the same for each column independent of column heigh, hence the variable *Irrigation Rate* should be adjusted for each column regarding to its heigh or better, the ore weigh loaded into it.

Reference for variable solution *Irrigation Rate* by each column height in this case is the project heap heigh lift of 8 meters and its *Irrigation Rate* of 5.0 L/h-m^2.

Ore preparation before load the columns, curing process and operation of each column are described to follow:

- **Agglomeration**: it was used an intermediate leaching solution (ILS) with next characteristics: Cu = 1.898 g/kg, free acid = 1.67 g/kg, total iron = 21.26 g/kg, Fe^{3+} = 10.76 g/kg and added sulphuric acid 5 kg/t reaching an ore final moisture around 6% (See Table 4).
- **Curing:** time curing for these columns was 3 days at ambient temperature.
- **Leaching period**: in this project and due to project area restrictions, the leaching period should be around 184 days.
- **Leaching solution**: it was used a raffinate solution which free acid was suitably adjusted. Characteristics of leaching solution are as follow: Cu = 0.25 g/kg, free acid = 20 g/L, total iron = 21.26 g/kg and a ratio Fe^{3+}/Fe^{2+} = 1.02.
- **Temperature**: columns temperature operation is 25 °C, maintained constant by means of an insulation cover and heat tracing.
- **Controls and chemical Assay**: every day of leaching cycle up to day 56 it was collected a sample per day to perform a chemical assay of copper, total iron, ferrous iron and additionally do measurement of pH, Eh and free acid. After day 56, samples for chemical assay were collected every five days up to day 184.

Irrigation regime was constant and continuous for each column from day 4 to day 184. Additionally, it was maintained in similar way a countercurrent air flow of 0.6 m^3/h-m^2.

TESTS RESULTS

To follow are presented the results obtained in these tests for the 184 days leaching period. This information is about copper extraction results, acid consumption, pH and REDOX potential among other parameters.

Copper Leaching

Once started the irrigation operation in each leaching column and after the tree curing days, solution took around other three days to start dripping into the container that collects the pregnant leaching solution (PLS) under the column. A sample was collected every day from this container to perform a chemical assay and solution control up to day 56, onwards and up to day 184, samples were collected every five days.

Copper extraction measured from first day that columns dripped PLS and during all leaching cycle are represented in curves shown in Figure 3 below.

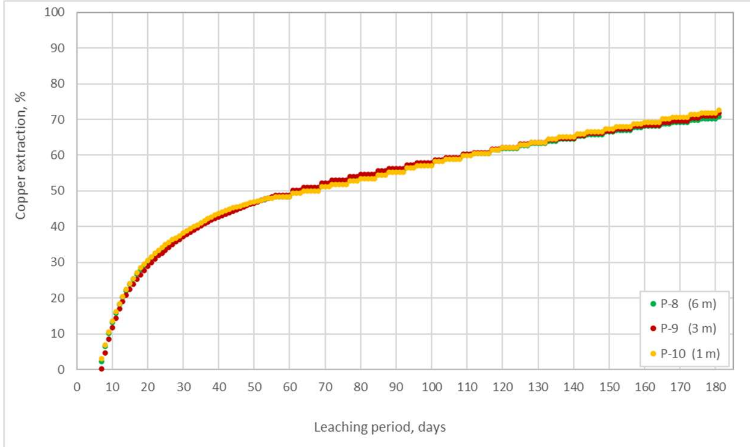

Figure 3. Copper extraction During the Leaching Cycle for Each Column

As can be seen in Figure 3, the copper extraction behaviour in each column is similar along the leaching cycle. Final copper extraction for each column has close values with a slightly greater extraction in the smaller columns, maintaining an inversely proportional relationship between copper extraction and heigh column: column 6m: 70.3%, column 3m: 71.0% and column 1m: 71.8%.

Acid Consumption

Regarding to the gangue acid consumption (GAC), initially the consumed acid was very similar in each column test, but around the day 56 after starting the test, the GAC began a different behaviour suggesting acid generation in the 1 m column as can be appreciated in Figure 4. As per the data obtained and shown in Figure 4 it is possible to note that the gangue acid consumption has a directly proportional relationship with column height (Figure 4a) once most of copper oxides were leached, it can be inferred observing the column tests kinetics in Figure 3 compared with the copper acid soluble (CuS) of sequential copper assay.

It should pay attention over the acid consumption, there is a different behaviour in function of column height. In this case, using an ore with secondary copper minerals as chalcocite and covellite and other sulphides as pyrite in addition to the copper oxides which the copper leaching is strictly based in a chemical reactions mechanism, it seems that when copper oxides are spent, start an sulphides oxidation mechanism that generate acid in the system and it appear as less acid consumption value along the leaching cycle (Figure 4a) or reducing the GAC regarding to copper extracted rate as is shown in Figure 4b.

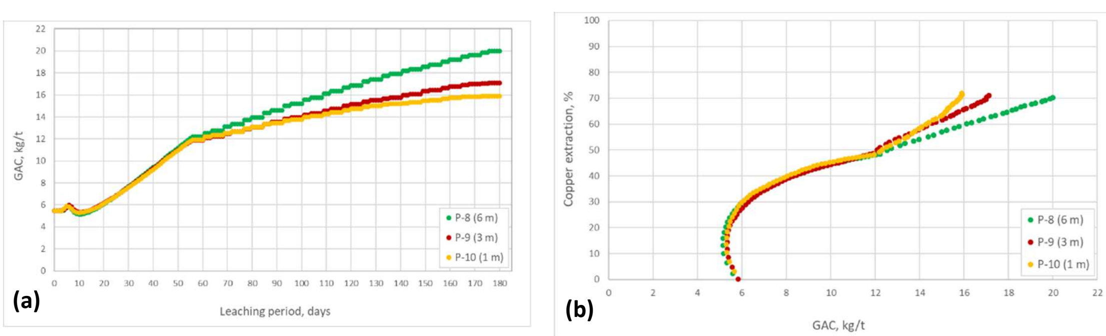

Figure 4. Ganga Acid Consumption by Each Column Test

Other Leaching Parameters

Main parameters that directly affect the copper leaching are the extraction kinetics and gangue acid consumption, but it depends on other parameters that are key to support good results and aid the understanding of kinetics and GAC behaviour. One of these parameters is the *Total Iron* (FeT) dissolved in the PLS (Figure 5a) and related to this and the quality of the bacterial activity is the ferric ion content in the PLS or even better the ferric ion to ferrous ion ratio (Figure 5b).

The *Total Iron* dissolved in PLS has an inversely proportional relationship with column heigh (Figure 5a). Despite the difference in *Total Iron* in the solution, the Fe^{3+}/Fe^{2+} ratio is very similar along the time in all three columns (Figure 5b).

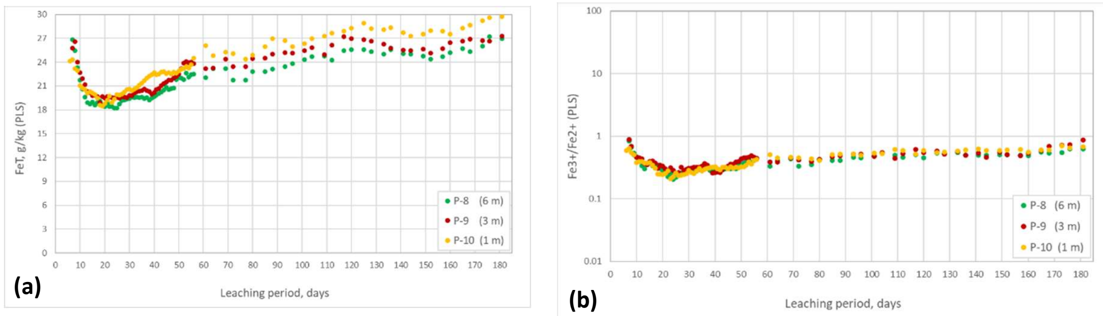

Figure 5. Total Iron and Ferric-Ferrous Ratio in PLS

The tendency is that as the columns are smaller, the acid consumption is less and therefore the free acid in the solution is higher as is shown in Figure 6a. Due to the Fe^{3+}/Fe^{2+} ratio is similar for each column independent of its height, the electrochemical potential or oxidation-reduction potential (ORP) is similar also for all columns as can be seen in Figure 6b. ORP values reported are regarding the Ag/AgCl electrode.

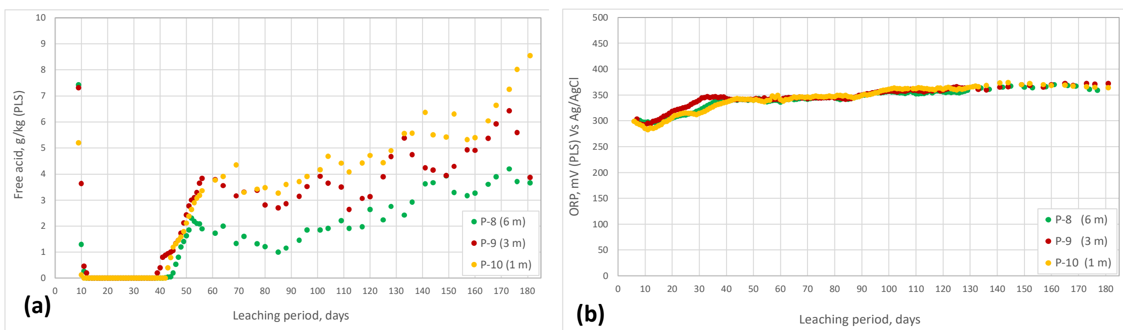

Figure 6. Free Acid and Electrochemical Potential in PLS

DISCUSSION

Copper extraction by acid leaching using different height columns and applying an adjusted solution rate in accordance with the column height (columns ranging from 1 m to 6 m) or even better regarding to the ore weight loaded in each column shown similar leaching curves or in other words, the copper extraction kinetics is equivalent in each case. It is highly recommendable in this type of tests is to use the ore weight instead the column height to reach more accuracy in results.

Despite that leaching curves are very similar for each column height, copper extraction at 184 days of irrigation is slightly different as can be seen in Table 5. It could be attributed to small deviations in operation, experimental error and the supplied air rate which was the same flow for all columns and perhaps should be treated in the same way of leaching solution rates. The main operating leaching parameters are reported in Table 5 or illustrated in Figure 7.

Although the copper extraction can be considered with similar results with a little difference in final copper extraction values (range of 1.8% among columns), the gangue acid consumption (GAC) has different behaviour mainly after leaching the copper soluble in acid (CuS) of sequential copper assay, it could be due to the different level of pyrite oxidation as consequence of air flow which is the same in all columns and consequently the lowest columns, so it would be receiving a higher rate of air per weight of ore. It is consistent with less acid consumption in shorter columns as well as the higher *Total Iron* concentration and *Free Acid* in the PLS. In the case of the Fe^{3+}/Fe^{2+} ratio and ORP, these variables are strongly related and despite of little variations in final values at 184 days, these curves along all leaching cycle has a similar behaviour.

Table 5. Test Results at 184 Days for Each Column

Column height	Cu recovery %	GAC kg/t	FeT g/kg	Free acid g/kg	Fe^{3+}/Fe^{2+}	ORP mV
6 m	71.2	20.4	26.5	4.3	0.6	364
3 m	72.3	17.5	26.9	4.7	0.9	374
1 m	73.0	15.9	28.6	7.0	0.6	368

It is important to note that although these tests were conducted under a bioleaching process, *Total Iron* in solution was high and there is an apparently important bacterial activity evidenced by the lower acid consumption in shorter column, the Fe^{3+}/Fe^{2+} ratio was under 1.0 in all columns. For variability test campaign it was reached a highly oxidative process with Fe^{3+}/Fe^{2+} ratio major than 1.0 and ORP higher than 450 mV (Ag/AgCl), so it is defined by the Nernst equation which can be used to determine one of the two values.

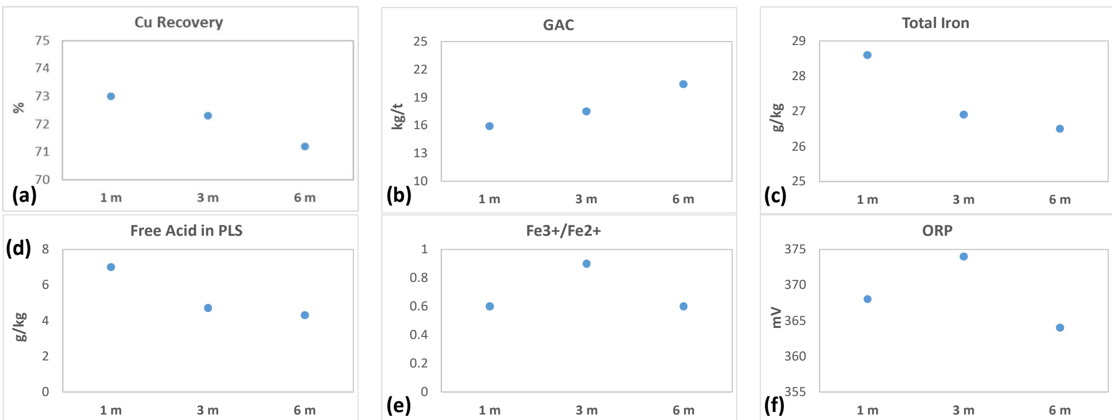

Figure 7. Graphic Representation of Test Results at 184 Days for Each Columns

CONCLUSIONS

- The findings in this study demonstrate that it is possible to obtain a similar copper leaching kinetics in short columns regarding to full-size column leaching that represent the heap lift (v. gr. 6 m). The key parameter to reach it is the implementation of the variable irrigation solution rate in function of column heigh or even better to ore weight loaded to the column. The *Solution/Ore* rate (m^3/t) is proposed as a main parameter to manage any test with different column sizes and to be used as scale-up factor to the industrial leaching. This is aligned with what was proposed by E. Rood (2000) and H. Lizama, et al. (2004).

- The copper extraction results obtained in this test can support the metallurgical variability program due that it is possible to use smaller sample weight for a column leaching test without any important bias in recovery or the necessity to a complex model for the copper recovery scale-up. It is well known that representative samples available from drill cores to perform a column leaching metallurgical campaign are not abundant in any project.

- Acid consumption presented a different behaviour of copper extraction, with an apparently acid generation mainly in shorter columns, it is possibly due to pyrite oxidation by Fe^{3+} ion and bacterial activity. Higher *Free Acid* concentration in PLS and lower GAC is aligned with higher *Total Iron* in the PLS and higher air to ore rate also.

- Together with variability metallurgical program should be carried out another test similar to this but paying special attention, furthermore of kinetics and variable *Irrigation Rate*, to which are the causes of variable acid consumption and related parameters as *Total Iron* in the solution and the oxygen dissolved which is related to the air injection flow rate.

ACKNOWLEDGMENTS

The authors would like to thank the staff and management of the Proyecto Trapiche and the VP of Projects Management and Innovation of BVN for their support and provision of data to prepare this paper. The views of the authors do not necessarily present those of the Company.

REFERENCES

1. Edwin A. Rood. Solution Application Techniques for Column testing, Randol Copper Hydromet Roundtable 2000. Randol International, Golden, pp. 49–52, 2000.

2. H.M. Lizama, J.R. Harlamovs, D.J. McKay, Z. Dai. Heap Leaching Kinetics are Proportional to the Irrigation Rate Divided by Heap Height. Minerals Engineering, 2004.

3. S.W. Robertson and P.J. Van Staden. The Progression of Metallurgical Testwork During Heap Leach Design. Hydrometallurgy Conference 2009, The Southern African Institute of Mining and Metallurgy, 2009.

4. J. Marsden, L. Todd and R. Moritz. Effect of Lift Height, Overall Heap Height, and Climate on Heap Leaching Efficiency. SME Annual Meeting Denver, Colorado - March 6-9, 1995.

5. Vaikuntam Iyer Lakshmanan, Raja Roy and V. Ramachandran Editors. Innovative Process Development in Metallurgical Industry - Concept to Commission, 2016.