Development of accurate metal production forecasts for a heap leach project using METSIM®dynamic simulation and defensible column leach testing data

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Abstract

Development of precious metals or copper heap leach projects typically follows a sequence of steps, from feasibility study through engineering, detail design, construction, and operation. Critical to the success of these projects is correct estimation of leach kinetics and heap design. The column leach tests performed in the laboratory to simulate the heap leach process are conducted on representative samples of the ore to be processed. The metallurgical data developed include the leach kinetics, which are determined using optimized leaching parameters. However, the leach data developed in a metallurgical laboratory do not typically reflect the true leach cycle and contact times experienced in the actual heap leach process.

Dynamic simulation of the heap leach process allows operations personnel to fill the gap. METSIM metallurgical simulation software is able to dynamically model heap leach processes for copper and precious metal ores. Incorporating defensible metallurgical laboratory column leach test data into a METSIM model allows for development of accurate metal extraction projections. These metal extractions are useful to forecast production on a monthly and annual basis and they may be part of a comprehensive dynamic model of a life-of-mine (LOM) heap leach. Reliable laboratory column leach test data and METSIM heap leach modeling provide a predictive tool that has proven valuable in the development and operation of heap leach projects.

Introduction

One of the most challenging tasks at a heap leach operation is the development of a production forecast. This information is usually required by management to set benchmarks for production. The amount of precious metal produced is directly proportional to the volume and tenor of the pregnant solution processed in the metal recovery plant.

The metallurgical department develops the precious metal leach kinetics by means of column leach testing. In this type of study, column tests are used to evaluate a heap leach process using a batch type of testing methodology. It is impractical to conduct continuous column leach testing for evaluation of a heap leach process in the laboratory. Therefore, a combination of column data and computer software must be employed for simulation of a heap leach process. PROWARE® has developed metallurgical simulation software for precious metals heap leaching. This paper outlines a methodology for developing defensible metallurgical data that may be used to develop accurate production forecasts using METSIM software.

Leach kinetics estimation

Practical aspects of a column leach study

Important technical and economic variables associated with precious metals heap leaching are well known, since this technology has been fully commercialized. The testing procedure employed by commercial firms tends to parallel processes utilized by large mining companies, since the unknowns relative to leaching chemistry and economics are the same in both cases. A typical testing program consists of mineralogical characterization, sample preparation, and leach testing. The test procedure may be simple or complex, depending on the desired outcome of the testing.

Sample origin

A project under development usually employs a competent geologist to identify and define ore horizons. In many instances, a commercial testing firm must rely on the client geologist to provide a description of the ore mineralogy. In these cases, it is of utmost importance that the testing personnel specifically state the condition of samples received and fully specify all sample composite instructions; this ensures that samples prepared for testing are representative of ore horizons in the deposit.

Ore mineralogy

The specific mineralogical nature of the samples to be tested may be thoroughly defined, completely unknown, or somewhere in between. If no mineralogical information exists, it is prudent to examine the selected samples megascopically and microscopically. This information contributes specific knowledge to the subsequent precious metal extraction task by identifying the existence of minerals that could impact processing decisions. Host rock components should also be identified, along with the consequent potential for reagent consumption. It is important to characterize the mineralogy of sulfide ores, since sulfide minerals tend to be associated with gold and exhibit distinctive leaching characteristics.

Initial ore characterization

Samples may be received in a variety of forms, including unsorted bulk samples, large and small diameter diamond cores, and percussion diamond drill cuttings. Samples that are used to replicate heap leach response in test columns are contacted for specific time periods with a defined lixiviant concentration. Characterization of samples is therefore critical to testing, and different samples will require slightly different pretreatment for column leaching.

Every ore type identified in the deposit should be subjected to an ore characterization test prior to inclusion into the column leach program. The initial characterization test varies from organization to organization, but usually consists of a bottle roll low cyanide concentration leach test conducted for 24 to 72 hours and using a sample split that has been reduced to a size distribution between 4,750 and 106 microns. This test yields important data about the expected ultimate precious metal extraction from the sample and the potential maximum reagent consumption. The metallurgical data allows testers to select initial test parameters to minimize the number of column leach experiments required for the project.

Bottle roll studies provide information about the maximum reagent consumption characteristics for different ore types. Experience has shown that, for many typical materials, the amount of sodium cyanide consumed in an industrial-scale leach operation will be a fraction of the quantity of cyanide consumed in a minus106 micron bottle roll test.

A refinement of the characterization bottle roll leach study is conducted in small diameter columns. These mini-columns are typically 75 mm in diameter and 1.6 m tall. Each column is filled with a carefully prepared sample consisting of approximately 10 kg of minus 12.5 mm crushed material. Columns are arranged in a matrix fashion and allow researchers to study a number of variables, including the following:

- agglomeration or no cure agglomeration;
- quantity of cyanide or binders added to cure; and
- cure time – the rest period after cure treatment.

The mini-columns are operated for 14 to 28 days (2 to 4 weeks), during which researchers macroscopically study the physical condition of the ore under different leaching regimes. Usually, one or two standard tests that are not treated with strong lixiviant prior to leaching are included in the experimental matrix for each ore. Behavior of the effluent solution during the rather short mini-column leach cycle helps to define the criteria for larger test columns, thereby reducing the number of large diameter column tests to a minimum.

Sample preparation for a column leach study

Ideally, the crushed ore sample in an actual column study should replicate a hypothetical differential increment column in a heap. In order to approach this ideal situation as closely as possible, the test sample should be sized and deposited in the column in a manner that avoids segregation.

The procedure used to reduce the size of test samples is important. Sloppy sample preparation procedures can result in the generation of confusing column leach data. A recommended sample preparation procedure includes crushing the entire test sample through the coarsest top size and screening the entire sample on a stack with a minimum of five sieve sizes. Each fraction should be stored separately in a covered drum. Individual column test charges are reconstituted by splitting representative sample weights of each sieve fraction and mixing the resulting smaller fractions.

Since the head sample assay will be used to determine the precious metal recovery, it is recommended practice to obtain the assay sample from individual fractions at the full weight at the standard column charge. For example, if a full column charge is 90 kg (typical for one 20 cm diameter by 1.8 m tall leach column), and if the minus 50 mm by plus 25 mm fraction is 12 weight percent, then 11 kg of minus 50 by plus 25 mm material should constitute a representative split of the original assay sample. A typical procedure involves reducing the entire 11 kg sample to 1.7 mm, thoroughly blending the minus 1.7 mm sample by repeated riffle splitting and then pulverizing several one kilogram riffle splits through 150 micron for duplicate assay. This procedure tends to be laborious. However, it provides reproducible feed size fraction assay samples. As well as crushing, screening, and separating size fractions from the original sample, it is recommended that finer crush sizes be developed from the master samples. This can be performed by stage crushing the proper weight of oversized material and redistributing the crushed product screen fraction. This entire procedure tends to replicate the particle size distribution that is experienced in industrial practice.

One of the most important elements of precious metal heap leach studies is the ability to generate duplicate ore columns with exactly equivalent size distributions. Consequently, a sample preparation procedure that will yield equivalent column samples from a master ore composite must be employed. It can be difficult and time consuming to produce equivalent size distributions for laboratory testing. Usually, the common cone-and-quartering sample splitting system is not adequate. Columns of exactly equivalent size distribution can only be assured if the dry master test sample is screened into specific sieve sizes and the charge for each column is reconstituted by reference to the direct weight of these fractions.

The geological and mineralogical character of most economic precious metal ore bodies changes substantially at different ore horizons. These differences may radically influence leaching characteristics. For a large ore body, it is prudent to perform column tests at equivalent size distributions on all major ore types. This means it is necessary to develop a preliminary mine plan to ascertain the schedule in which various ore horizons are to be extracted. It may also be useful to prepare composite samples which represent one-, two-or three-year increments of ore production. If development of the ore body is to be partially or fully financed, lending institutions are always interested in the sequence of cash production for the project.

Sample agglomeration

Agglomeration is a condition in which individual particles of a crushed mineral product loosely adhere to one another. Complete agglomeration is a condition in which even the finest particulate fractions present in a sample are incorporated into loosely bound aggregates.

A simple laboratory agglomeration procedure consists of placing the individual size fractions of the sample in a bucket or small cement mixer with a binder, such as Portland cement and lime, water (or a cure solution), lixiviant solution, and/or surfactant reagents, while slowly rolling the solid material. After a certain quantity of liquid has been added (usually between 4 and 10% by weight) the solid material will form loosely adhering particulate aggregates or agglomerates. This agglomerated material can be charged carefully into a column of any height avoiding segregation within the column.

It is recommended that initial tests should always be conducted using agglomerated ore samples, especially if it is anticipated that ore will be crushed prior to leaching. Operating permits usually contain regulations regarding levels of particulate emissions surrounding the size reduction and materials handling facilities. As a result, it could be argued that ore samples should be tested in both agglomerated and non-agglomerated conditions.

Particulate (dust) emissions are commonly abated by applying water or barren solution directly on to the material being crushed. These solutions are usually added as a mist or spray at truck dump pockets and material handling transfer points. The quantity of water used is typically judged by the disappearance of dust at the point of application. This water quantity is also the level at which crushed material becomes agglomerated. For this reason, it is likely that ore that is reduced through at least a primary crusher will reach a heap leach pad in partially or fully agglomerated form.

If the ore to be leached is crushed through a single primary stage, this provides an opportunity to add a cure solution. In actual practice, the cure solution may be applied at any cyanide concentration consistent with the maximum concentration desired in the pregnant solution. This solution may be added as a spray at conveyor belts, at transfer points, or in an agglomerating drum.

In the laboratory, a precisely measured volume of cyanide solution is carefully sprayed directly into the agglomeration device prior to charging the ore into the column. The optimum quantity of sodium cyanide added in the cure pretreatment can only be determined through column experimentation. The cure dosage will depend upon crush size and ore mineralogy (sulfide, oxide, or mixed). Mini-column testing will reduce the number of large-scale tests required for clear definition and optimization of the important leach parameters.

Column leach test procedure

The column leach test procedure is relatively simple. Lixiviant solution (artificial or mature) is introduced at a constant flow to the top of the column and collected at the bottom. In larger diameter columns, the lixiviant may be distributed equally over the surface of the ore. The lixiviant solution must be delivered at a constant flow rate at all times for the duration of the test program.

Many different devices have been used to feed the lixiviant solution to the column, including intravenous drip apparatus, syringe pumps, constant head tanks (with or without timing devices), peristaltic pumps, and various types of positive displacement pumps. Although more expensive than most solution application devices, electronically actuated positive displacement diaphragm pumps are recommended for column irrigation.

The leach solution percolates the column and discharges as effluent solution. The effluent solution is gathered on a periodic basis, the volume is measured, and it is then assayed for elements and ionic species of interest. The test procedure is terminated either after a specific number of days have elapsed or when the column effluent no longer contains measurable quantities of soluble precious metal. The column is then drained, washed with water, and discharged. The leached residue is usually dried, weighed, screened into specific sieve fractions, and prepared for assay to determine insoluble losses.

Column testing can produce large amounts of data. The usual procedure is to use a computer spreadsheet and database management software to store and manipulate this information. Handling information in this manner is convenient for experimenters since interim progress reports are generated in a straightforward fashion.

At the termination of the leach test, the final column height is noted together with volumetric information associated with the wash and drain cycles. The leached residue is screened and assayed for elements of interest, particularly gold and silver. The column test information provides important test parameters, such as overall precious metal extraction and reagent consumption. Manipulation of this information also allows for the development of particle size degradation.

Test variables and parameters

Critical leach parameters commonly evaluated in the course of a column leach study include cure solution rates, application, and concentration. The cure solution may be added by a top-down methodology if it is anticipated that the ore will be leached at a run-of-mine (ROM) particle size distribution. If it is anticipated that the ore may be crushed, then the cure may be added during the agglomeration procedure.

The optimum cyanide quantity and concentration for the cure technique must be determined by experimentation. For many ores, the expenditure of time and money associated with this experimentation is worthwhile. A substantial reduction in the cyanide consumption relative to leaching without the cure technique may be realized as a result of the tests. The initial cyanide dosing used in the cure test is usually derived from the ore characterization test previously described.

The aging of ores upon extraction influences cyanide consumption and cure application. The impact of cure aging can only be investigated through test leach columns. On some silver ores, a considerable enhancement in silver disengagement rate and percolation characteristics have been observed when the ore columns are aged for periods from 5 to 15 days after a cure pretreatment. The application of binders improves porosity in the agglomerated material, assisting the cure process further.

Crush size

Commercially available crushing equipment tends to produce specific size distributions when operated in open circuit. These size distributions can be modified (usually at the expense of throughput) by operating the same crushing devices in closed circuit with classification screens.

Separation efficiencies on grizzlies and screening equipment are imposed by the ore size distribution, hardness, and moisture content. Recall that most modem crushing plants are required to operate within strict dust emission guidelines, and this restriction results in the production of a moist final product which is partially or fully agglomerated. The final product from each crushing stage depends upon the specific equipment assemblage, which is usually a function of design throughput. Typical top size distribution ranges have been developed through experience and are available in the literature provided by crushing equipment manufacturers.

Commercial crushing equipment tends to produce a rather narrow range of sizes, depending upon the circuit configuration selected. Ore sample top sizes are limited to100, 50, 25, and 12.5 mm, which covers the size ranges that are readily produced by conventional crushing facility equipment arrangements. If the quantity of available sample is limited, the test charge can be crushed to 12.5 mm top size and subjected to the previously described standard column leach procedure. If an acceptable extraction level results from this simplified test, coarser size distributions can be investigated when additional sample becomes available.

The data generated by size distribution studies may be presented in a number of formats. One option is a bar chart presenting the percentage of precious metal extraction by screen fraction. A depletion in weight for each of the coarser size fractions when leach feed is compared to leach residue is a common observation in column leach analysis. Presentation of data in this fashion will allow for development of economic parameters, which will indicate the optimum crush size.

Leach testing on different size distributions provides other valuable data as well. A plot of the percentage of precious metal extracted versus leach time for two separate ore size distributions may be prepared for comparison. Analysis of these data allows researchers to predict the precious metal disengagement rate and develop optimum heap placement and irrigation cycles.

Column diameter and height

The diameter of the test leach column used and the height to which the column is filled are influenced by several considerations. If only a small quantity of sample is available, small columns are used to conduct scoping studies. This situation is common when the only sample available from a specific ore horizon is derived from a small diameter diamond drill core. For test material top size limited at 12.5 mm, samples as small as 4 kg in total weight can be studied in 50 mm diameter by 1.2 m tall leach columns.

A rule of thumb relating maximum ore particle size to column diameter has been derived from sampling theory. In general, the diameter of the leach column should be three to four times larger than the maximum dimension of the largest particle in the test charge. Columns having the same size distribution but differing heights may exhibit different precious metal extractions with time and always have different pregnant liquor assays. When larger quantities of ore become available, a more or less standard leach test requiring 90 to 360 kg per column charge can be conducted in 150 to 300 mm diameter columns with an ore height varying between 1.5 and 3 m. Larger scale testing is always necessary and recommended to fully define all the leach parameters required to develop the design criteria for the project.

It is not unusual to conduct 6.0 m tall corroborative leach tests in columns up to l m in diameter. Test charges for this type of study will vary between 300 and 6,400 kg. These large-scale tests are designed to yield sufficient effluent (10 to 80 L per day) to operate an associated metal recovery system to fully quantify expected precious metal recovery and reagent consumption. Although column studies can be conducted on ore samples as small as 4 kg, the development of engineering design criteria requires the acquisition of larger ore samples. Leach columns ranging from 0.2 to 1 m diameter by 6 m tall charged with approximately 300 to 6,400 kg of ore typically replicate commercial results. Columns larger than this size are commonly used to corroborate previous studies or to produce a large quantity of pregnant solution for subsequent precious metal extraction testing.

Irrigation rate

There has been a concerted effort in the precious metal heap leaching industry to diminish the average heap irrigation rate. Many gold and silver properties irrigate the heap at a higher flow rate (for example, 12 L/hr/m^2) for an initial 14 to 21 day leaching period in order to quickly recover the most amenable portion of the precious metal content of the ore. After this time has passed, a lower irrigation rate (sometimes as low as 1.2 L/hr/m^2) is then utilized for the remainder of the leach cycle. This procedure tends to maximize the precious metal assay and minimize the volume of the pregnant solution to be treated in the metal recovery plant.

Strategies required to minimize the pregnant solution volume produced from precious metal heap leach operations have included cyclic altering of the irrigation rate as mentioned above, intermittent (on-off) leaching schemes, and recirculation of solution generated near the end of the leach cycle through an intermediate solution catchment. All of these strategies can be replicated in the laboratory, provided that there is a sufficient quantity of representative ore available to constitute the required number of necessary leach columns.

Although the typical irrigation rate used for precious metal leaching is 12.2 L/hr/m^2, specific applications at volumetric flows greater or less than this rate are well known. It is necessary that each ore under study be subjected to scoping tests, which involve variation of the irrigation rate. It has been demonstrated through column experimentation that, for certain materials, there is an optimum solution application rate at which precious metal extraction is maximized.

In a column leach test operation, the flow rate is the single most difficult variable to continuously control. Utilization of small columns (those less than 100 mm in diameter) necessitates the employment of very low flow rates. If the proper irrigation rates are to be achieved, maintenance of these low flow rates over a period of weeks or months is also required for a successful column leach test. Frequent surveillance and expensive pumping equipment will usually maintain a flow rate within 5% of the desired level. If substantial variations in daily flow rate are experienced, only cumulative flow may be reported to mask the daily flow differential. Consequently, daily flow data must be included in the experimental report so that an independent judgment can be made relative to the precision of the irrigation rate.

Lixiviant concentration

Column leach tests are also useful in evaluating the cyanide concentration used in a heap leach process. Study of this parameter will result in significant savings in sodium cyanide and enhanced leach kinetics. Silver dissolution has been consistently shown to be sensitive to cyanide concentration. Silver mineralization requires a cyanide concentration of at least 500 mg/L free cyanide. Gold dissolution, however, may be achieved at lower cyanide concentrations.

Heap design criteria

Leach pad capacity

Before dynamically simulating a heap leach, a three-dimensional structure representing the ultimate heap design must be generated. METSIM has the tools to either build a block model directly, through manual input of the size and shape of each lift, or to import survey and/or AutoCAD drawings. Upon completion of this “wire-frame” heap, METSIM then uses the material specific gravity and bulk density, along with the volume of the heap, to calculate the total solids capacity. In the case of dynamic or on/off pads, this capacity represents the total live capacity of the heap. Figure 1 shows the plan view of two heap configurations in METSIM. A permanent stacked pad is shown in the bottom right of Figure 1. The permanent pad was generated using AutoCAD contour lines.

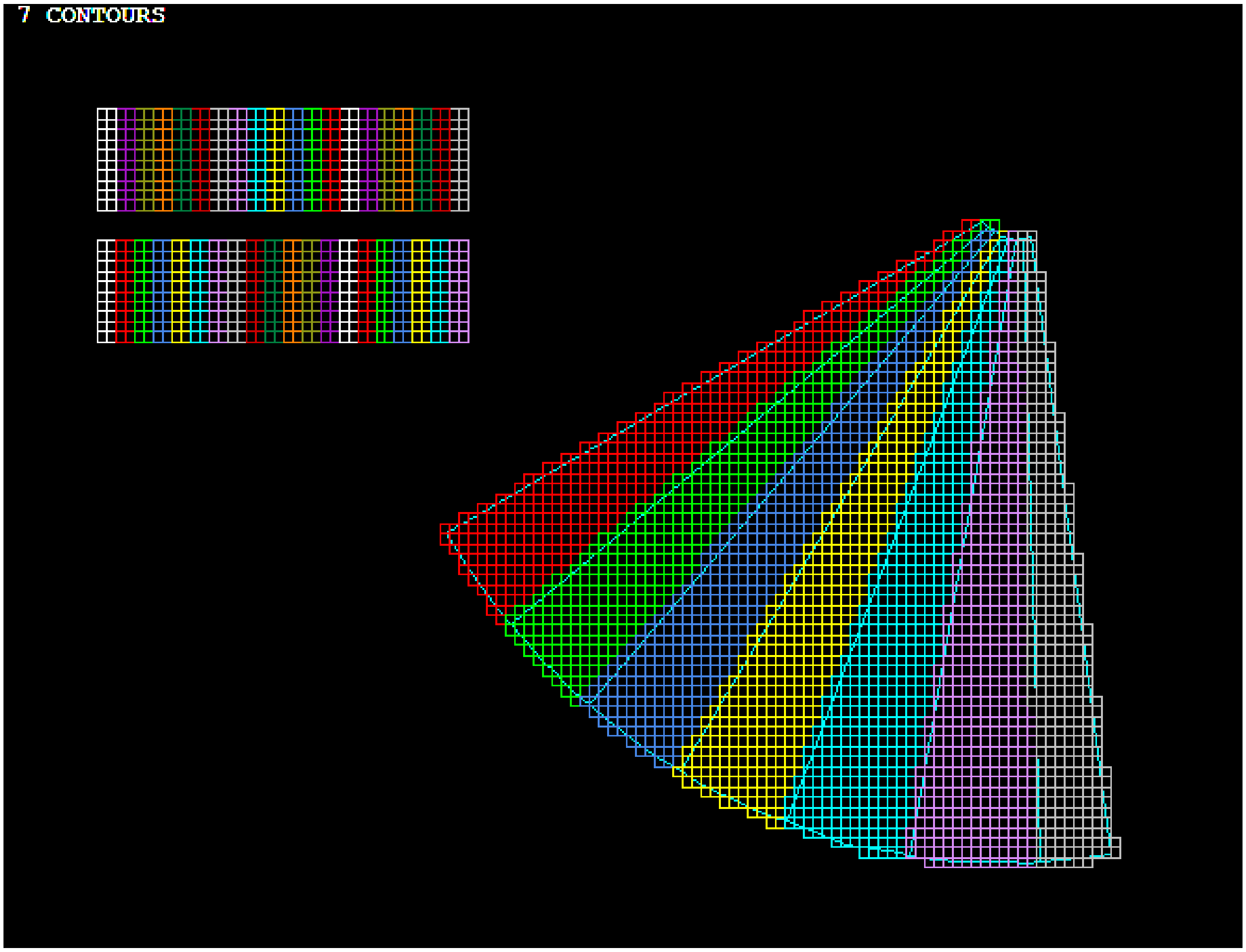
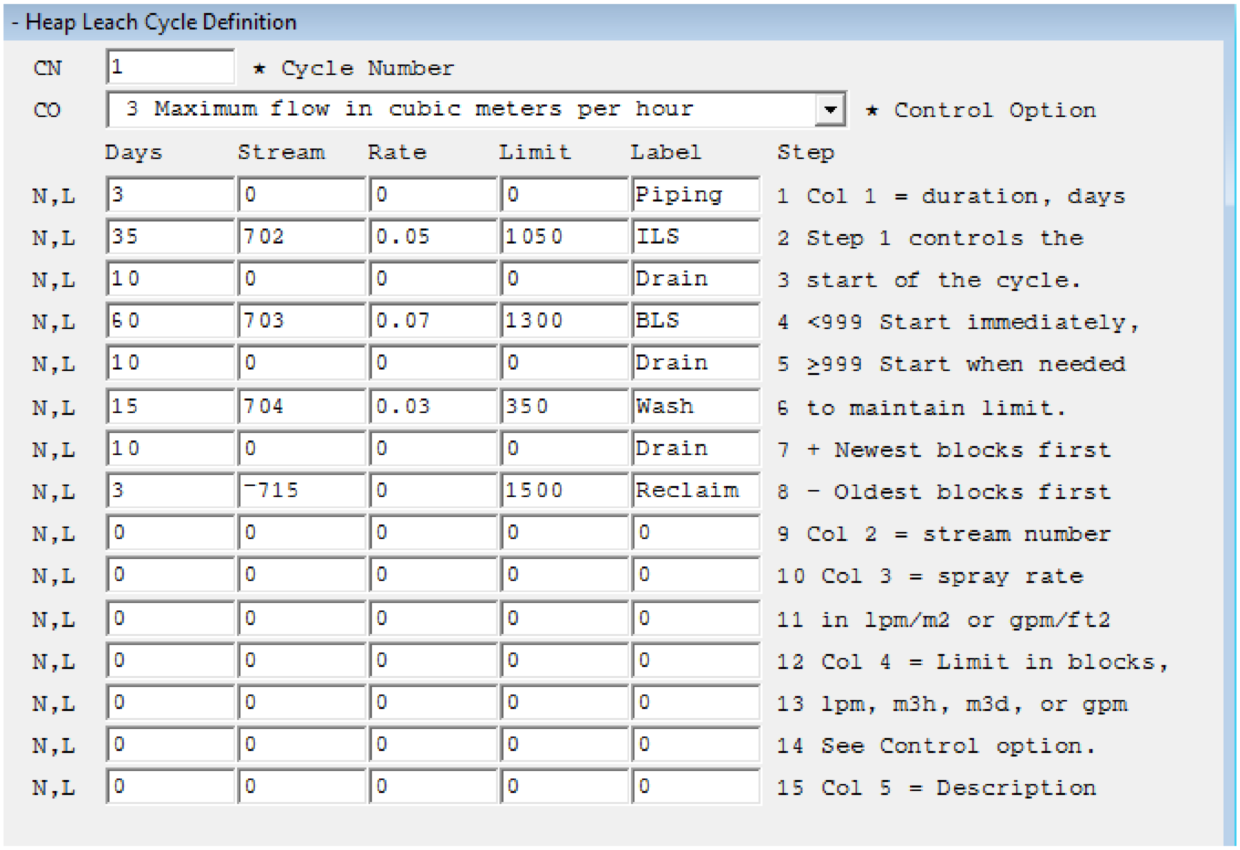


Figure 1: Example of a plan view of two heap configurations in METSIM. An on/off configuration built through manual input of cell size and number of cells is seen in the top left portion of the screen

Leach cycle

As Figure 1shows, the heap is broken into color-coded cells. A cell represents an area of the heap that is to be piped and leached as a single unit and may or may not drain to a specific location. Each cell in METSIM is assigned a leach cycle, which may include up to 15 different steps, and includes the length of time and application rate, as seen in Figure 2.



CN 1 ★ Cycle Number

CO 3 Maximum flow in cubic meters per hour ★ Control Option

	Days	Stream	Rate	Limit	Label	Step
N,L	3	0	0	0	Piping	1 Col 1 = duration, days
N,L	35	702	0.05	1050	ILS	2 Step 1 controls the
N,L	10	0	0	0	Drain	3 start of the cycle.
N,L	60	703	0.07	1300	BLS	4 <999 Start immediately,
N,L	10	0	0	0	Drain	5 ≥999 Start when needed
N,L	15	704	0.03	350	Wash	6 to maintain limit.
N,L	10	0	0	0	Drain	7 + Newest blocks first
N,L	3	-715	0	1500	Reclaim	8 - Oldest blocks first
N,L	0	0	0	0	0	9 Col 2 = stream number
N,L	0	0	0	0	0	10 Col 3 = spray rate
N,L	0	0	0	0	0	11 in lpm/m2 or gpm/ft2
N,L	0	0	0	0	0	12 Col 4 = Limit in blocks,
N,L	0	0	0	0	0	13 lpm, m3h, m3d, or gpm
N,L	0	0	0	0	0	14 See Control option.
N,L	0	0	0	0	0	15 Col 5 = Description

Figure 2: Example of a heap leach cycle in METSIM

As the heap is filled with ore during the simulation, the flows to and from each cell are controlled by the leach cycle. Flowrates are then recorded for all Intermediate Leach Solution (ILS), raffinate, drainage, and other streams for each day. Leach cycles may be created for each cell in the heap, or all cells may be assigned the same leach cycle, allowing the user complete control over all solution flows in the circuit.

Leach pad drain configuration

The control of each drainage stream may have a large impact on downstream plant designs and total metal recoveries, and may ultimately influence project success or failure. Using METSIM, numerous drainage configurations may be evaluated to optimize solution flows over the changing conditions of the project life. To best manage the drain design, METSIM allows for each cell to drain to a designated location or stream. For dump leach operations, this may be a single pond for all cells in the heap, whereas on/off operations may include a specific drainage pipe for each cell. Each of the drainage streams will witness varying flows and solution tenors for each day of operation and must be controlled accordingly. Figure 3 shows a heap leach process flow diagram in METSIM where streams 707,708, and751-770 represent heap drainage.

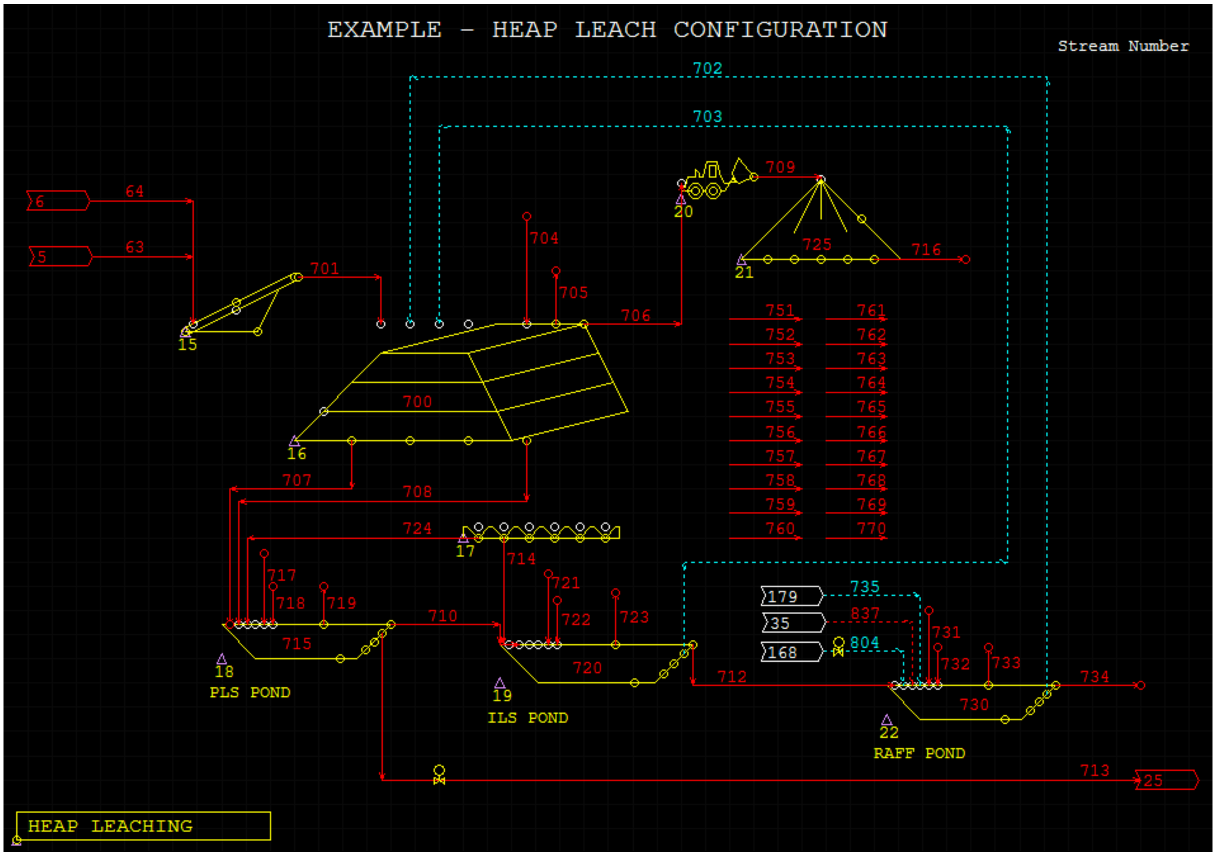


Figure 3: Process flow diagram for the heap leach drainage and pond system in METSIM. Streams 751-770 represent internal drainage streams assigned to specific cells

Using the heap leach drain unit operation (17 in Figure 3), drainage streams may be diverted based on cut-off grades, total flow capacities, or lixiviant stream number. Drainage rates and field moistures, obtained through testwork, are also included for each cell in the model. Dynamically simulating various piping designs and operating set points allows for thorough examination of all options and their results, therefore leading to better project performance.

Solution management and water balance

Once the design for the solution systems to and from the heap has been determined, the task of solution management and water balancing over the life of the mine is manageable. The lixiviant and drainage streams are recorded each day of the simulation as are all water make-up streams, daily precipitation to the heap and ponds, daily evaporation from the heap and ponds, and all recycle stream flows from downstream processes. Every unit and stream is balanced throughout the simulation. Appropriate plans can then be made to handle wet and dry seasons and major weather events.

Heap leach simulation

Leach kinetics extrapolation

Once the test-work has been completed and the heap system has been designed, these two critical pieces are merged to track solution tenors and metal recoveries. Initially, all column data is entered into METSIM. The best curve-fitting algorithm available is included in METSIM and used to determine the recovery rates based on the given data. For a single ore sample, various recovery rates are possible, and these have a major impact on the process. Figure 4 shows a curve fit performed in METSIM, where two recovery rates are applied to fit the data points.

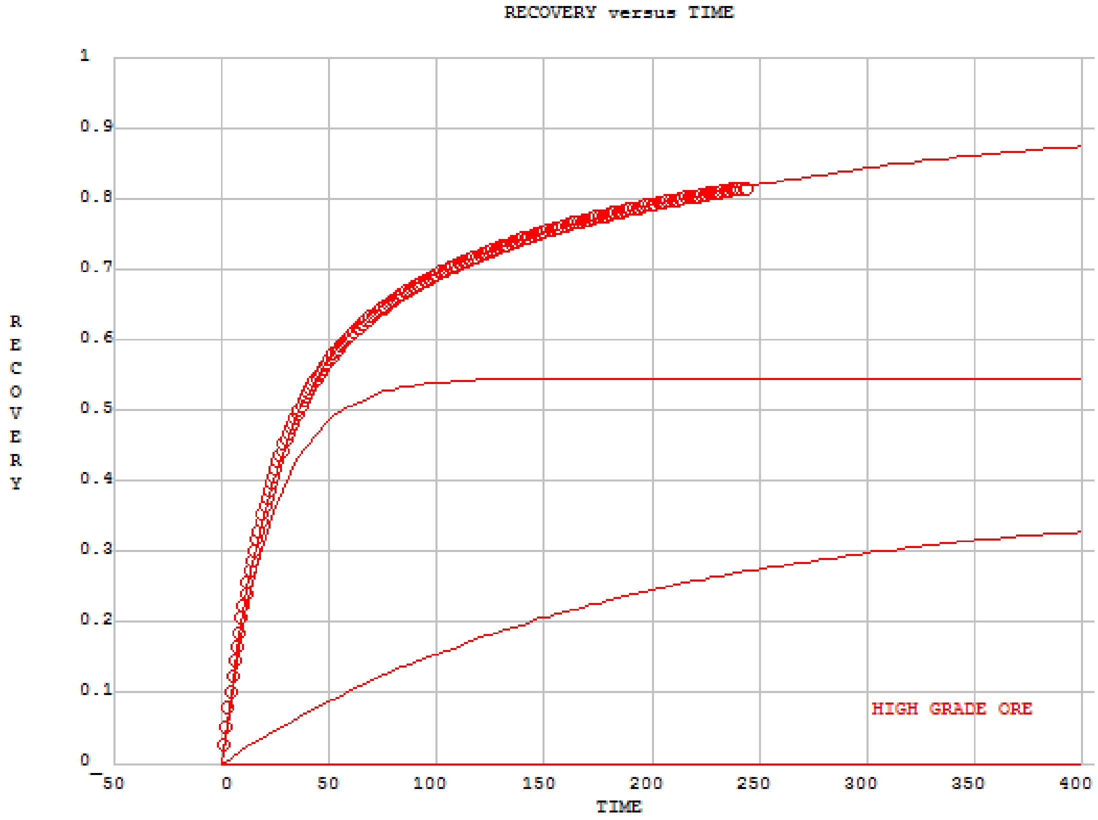


Figure 4: Curve fit in METSIM using two rates

Circles represent data points from column testwork, while the top curve-fit line is the overall recovery curve. The middle line in Figure 4 represents the fast rate recovery curve, and the bottom line represents the slow rate recovery curve.

Each recovery rate is then applied to a specific component in the model based on the ore type, particle size, or mineralogy. During the dynamic simulation, METSIM analyzes the solid and aqueous contents of each cell in the heap and applies the appropriate recovery rate. In the event that a reagent is not available (i.e., has been completely consumed), any reaction that requires that reagent will have no recovery. This method of calculating and tracking reaction extents ensures that operating conditions are taken into consideration when determining ultimate metal recoveries.

When multiple tests on the same ore type yield slightly different results, it is necessary to further examine the cause of the differences. By plotting several tests against each other, as shown in Figure 5, it is possible either to determine the most representative data for calculating recovery rates, or to average the curves into a single curve that represents overall recovery.

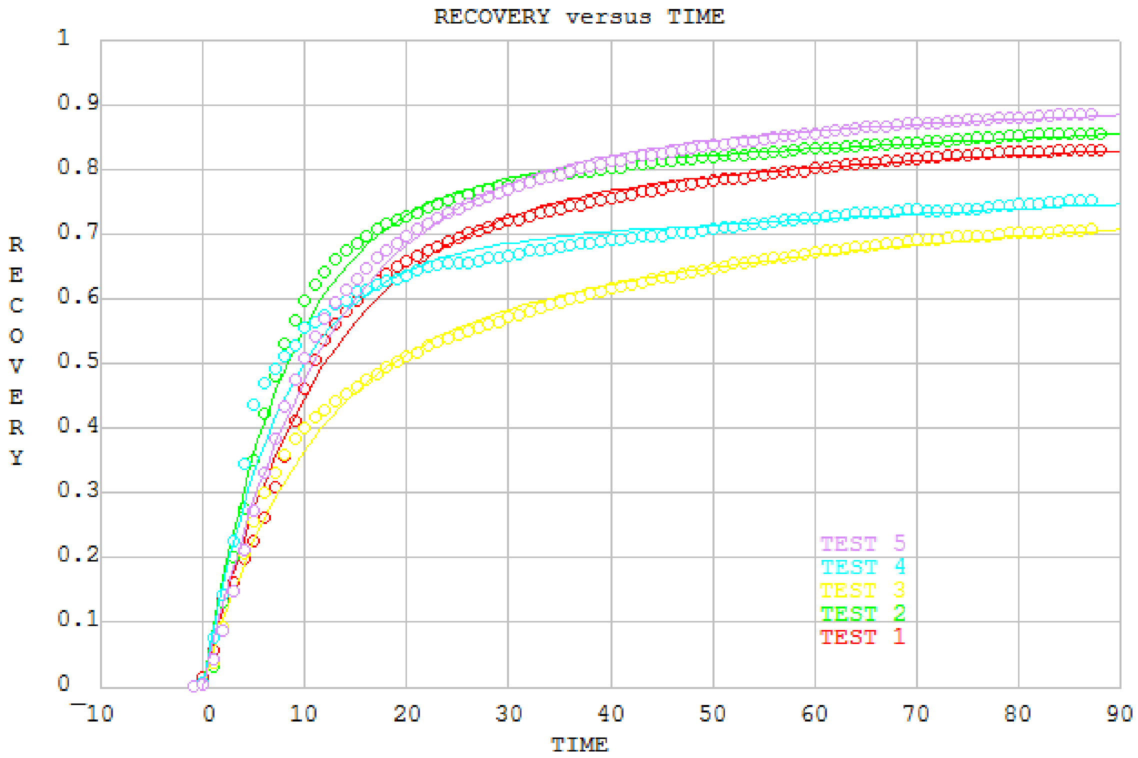


Figure 5: Recovery curves from five different tests plotted together in METSIM

Spreadsheet models become unmanageable with the large number of factors influencing the behaviors of such plants. Through curve fitting of test column data and dynamic simulation using METSIM, accurate process simulation and determination of the recoveries of heap leach operations is possible.

Conclusion

Development of accurate precious metals production forecast requires the following:

- Samples that are representative of the production period under evaluation (The production period could range from selected years of production to LOM for the project.)

- A set of metallurgical procedures that have been tried and proven to simulate actual practice as closely as possible in a metallurgical laboratory
- Evaluation of all the leach parameters to be included in the design criteria for the project

If a heap leach project is already in operation and the quality of the data is not suitable for the METSIM model, it is recommended to conduct a column leach study using full size columns. The samples to be used in the study should be representative of current production. The metallurgical data developed in conjunction with a dynamic model will provide the desired production forecast for the project. For a heap leach facility already in production, it is a good idea to develop a dynamic model to corroborate current or past production to ensure that the leach kinetics employed simulate the heap leach process.