

## **BASE METALS HEAP LEACHING APPLICATIONS AND PROCESS PARAMETERS**

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### **ABSTRACT**

The heap leaching of base metal ores can be applied within a number of different scenarios, each requiring its own set of parameters to be determined during the metallurgical testwork programme. The occurrence of acid-gangue reactions and its concomitant precipitation reactions is a factor common to all cases, and requires that the optimal irrigation acid strength be found that optimises the combination of extraction kinetics, acid consumption and possible premature blinding of the heap due to precipitation reactions. For the heap bioleaching of base metal sulphide ores the oxygen requirement needs to be determined for the design of the aeration system, and the operating conditions employed need to also facilitate bacterial growth over and above the acid strength optimisation mentioned above. For the heap bioleaching of chalcopyrite, the need to preserve heat in the heap becomes yet a further parameter of critical importance. For the heap leaching of uranium ore a choice is required between either chemical or bacterial oxidation, based on economic and processing factors. Frequently the operating parameters need to be determined for a circuit in which heap leaching is combined with tank leaching and/or pressure leaching. The processing implications and metallurgical testwork approach for each case is discussed.

## **1 Introduction**

In order to generically cover most of the applications to which heap leaching can be applied, the applications are classified as follows for the purpose of this article:

- a. Acid soluble oxide ore: of which the heap leaching of oxide copper ore with mild sulphuric acid solution is the most widely applied, but the leaching of the oxides of metals such as zinc or nickel can also be classified under this application.
- b. Readily leachable sulphide ore: of this application the heap bioleaching of chalcocite ores is the most widely applied, but the leaching of the relatively readily soluble pentlandite (Ni-sulphide) and sphalerite (Zn-sulphide) are other examples that would fit under this category.
- c. Refractory sulphide ore: the most widely published application in this category is the heap bioleaching of chalcopyrite ore, where a popular approach is to maximise heat accumulation to raise the heap temperature to accelerate the leaching kinetics of the relatively refractory chalcopyrite mineral<sup>(1)</sup>. Copper enargite ores would also fall into this category.
- d. Uranium ore: Uranium most commonly occurs as oxide minerals that require oxidative leaching for solubilisation, and elevated temperatures are employed to accelerate the leaching kinetics in the tank leaching of milled uranium ore. It can therefore not be classified under one of the other application categories mentioned above, and is therefore treated separately. The steadily continuing improvement of the uranium market currently being observed necessitates the revival of consideration of the possible alternatives for uranium ore processing.

The rest of the article endeavours to identify those heap leaching process parameters which would be of critical importance to each of the respective applications, and the process design specifications which would be set by those parameters. It is shown that the criteria that determine the process design specifications are different for the various applications. This is particularly true for the specification of the acid concentration of the irrigation liquor where for example the stoichiometry of oxide metal leach reactions require acid addition whereas metal sulphide dissolution reactions do not. On the other hand consideration of the pH environment for bacterial growth is a consideration in sulphide heap leaching but not in oxide heap leaching. Clearly the different criteria for acid addition can be expected to lead to widely different acid strength specifications. But similarly the combinations of criteria that set the specifications for aeration and for rest periods vary from one application to another. The central theme is that rules-of-thumb can not be relied upon for the determination of heap leach process design specifications.

## **2 Discussion of Applications and Process Parameters**

### **2.1 General**

A summary is provided in Table 1 of the way in which the major process design specifications affect various heap leach operational/performance parameters, and to which of the applications those are relevant or not.

Of all design specifications, the acid strength of the irrigation liquor potentially affects more operational/performance parameters in the heap than any of the other specifications, namely

- In the case of metal oxide leaching, acid is required as part of the dissolution reaction,
- All cases are affected by the reactions that occur between the acid and gangue minerals, in terms of acid consumption (the stronger the irrigation acid, the greater the extent to which gangue minerals are dissolved) and in terms of the threat of blinding of the heap by the products of the re-precipitation of the solubilised gangue constituents (the greater the extent of acid-gangue reactions, the greater the potential for the formation of gypsum, silica, jarosite and other precipitates in the heap).
- In all cases that rely on bacterial action in the heap, due cognisance needs to be taken of the effect of the acid concentration in the irrigation liquor on the pH environment in the heap, since the micro-organisms are sensitive to pH.
- In all cases that rely on oxidative leaching via the ferric ion, a pH environment that favours at least minimal ferric iron solubility is obviously required.
- Furthermore, in all cases the integration of the heap leach step with the downstream unit operations (such as solvent extraction) and possibly with other plant (such as a tank or pressure leach step as part of a split-circuit design) is clearly an important criterion for the specification of the acid concentration in the irrigant solution.

A thorough understanding of the mineralogical composition of the ore (in terms of both valuable minerals as well as gangue minerals), as well as the leach reaction kinetics and acid consumption under a range of operating conditions, is required to determine the optimal process acid strength specifications.

The system of “0”, “1” and “0/1” symbols whereby the relevance of the various parameters to the different applications are indicated in Table 1 should be mostly self-explanatory, and the reasons for the relevance or not should be obvious. But those process parameters that are relevant to all cases (showing “1” after the parameter under all four leaching application headings), and those instances where parameters could or could not be relevant (indicated by “0/1”), warrant further discussion, (apart from the parameters affected by acid strength, which have already been referred to above).

**Table 1. Summary of Process Parameters Affected by Design Specifications**  
(0=the parameter is not relevant to the application, 1=is relevant, 0/1=could be relevant)

Process Design Specifications	Process Parameters Affected	Heap Leaching Applications			
		Acid Soluble Oxide Ore	Readily Leachable Sulphide Ore	Refractory Sulphide Ore	Uranium Ore
Acid content in irrigant solution	Metal dissolution reaction	1	0	0	0
	Gangue dissolution and precipitation	1	1	1	1
	pH for bacterial growth	0	1	1	0 / 1
	pH for ferric iron solubility	0	1	1	1
	Integration with downstream or split circuit	1	1	1	1
Air supply	Oxygen for bacterial growth	0	1	1	0 / 1
	Aeration-to-Irrigation ratio for heat accumulation	0	0	1	1
Rest periods	Drainage tenor control	1	1	1	1
	Improved aeration	0	1	1	0
	Manage precipitation reactions	1	1	1	1
Chemical oxidant addition to irrigant	Irrigant redox potential	0	0	0	0 / 1
Sulphide admixtures to ore	Acid and/or heat generation potential	0 / 1	0 / 1	0 / 1	0 / 1

## **2.2 Rest Periods**

The term Rest Periods refers to the practise of periodically interrupting the supply of irrigation liquor for any length of time before resuming irrigation. It is fairly widely accepted as a potentially useful operational variable in heap leaching, but possibly not equally widely applied as a standard practise and not fully exploited for its potential benefits, and the effects of rest periods on the fluid flow dynamics and transport phenomena in a heap have certainly not been fully described.

The most obvious process parameters that can be manipulated by the use of rest periods appear in Table 1, namely

- Control of the soluble metal content in the heap drainage solution. It has been found that, when the soluble metal concentration in the drainage from a heap reaches an uneconomic level, leaching in the heap will continue for some time during a rest period, and after resuming irrigation the heap will once again yield an economic soluble metal tenor for some time. In this manner the useful economic life of a heap can be extended.
- Improved aeration: oxygen uptake measurements during heap bioleaching laboratory experiments have shown that the uptake of oxygen rises during rest periods, signifying increased bacterial activity<sup>(2)</sup>. This phenomenon is probably related to the creation of voids during the drainage of liquor from the heap during the rest periods, and is obviously very relevant to all heap leaching applications that rely on bacterial action.
- To manage precipitation reactions: since the liquor content in a heap diminishes during a rest period, while the leaching reactions do not cease to proceed, conditions of super-saturation can develop, thereby encouraging precipitation reactions in the heap. This mechanism could therefore be employed to exert a certain extent of control over the rate of precipitation in the heap, to ensure gradual precipitation opposed to having a catastrophic precipitation event after an extended period of dissolved salt build-up.

Once the mineralogical, chemical and leaching characteristics of an ore are known, a preliminary rest period approach can be formulated, but its efficacy needs to be verified by closely monitored experimental trials.

## **2.3 Sulphide Admixtures**

Pyrite typically occurs in ores treated by heap leaching. Although pyrite does not contribute valuable metal values, and upon oxidation it yields iron that poses a jarosite precipitation hazard, and in aerated heaps its oxygen demand requires additional aeration energy, its presence in ores also holds the following advantages:

- Iron acts as an important intermediary electron carrier in sulphide oxidation reactions, and pyrite is an important source of such iron.
- The gangue reactions occurring during the heap leaching of whole ores invariably result in a net acid demand in the heap, and the oxidation of the pyrite content of the ore is probably the cheapest source of acid available.

- In those cases that rely on elevated heap leach temperatures (namely the heap leaching of refractory sulphide ore and of uranium ore), the oxidation of pyrite provides a very cheap source of heat.

Therefore, in any of the possible heap leach applications, it is possible that the addition to the ore of an external pyrite-rich material has to be considered to augment the natural pyrite content, either for the purpose of acid generation, and/or for the purpose of heat generation in the heaps.

The need for such an admixture can be determined by simple stoichiometric calculation, but its efficacy needs to be verified experimentally.

## **2.4 Uranium Ore**

For the heap leaching of sulphide ores (typically copper sulphide ores), the oxygen demand is of the order of several kg per tonne of ore. The use of chemical oxidants (such as hydrogen peroxide) to effect sulphide oxidation would not be an economic option in those cases, and bacterial oxidation aspirated by the blowing of air into the bottom of the heaps has emerged as the most economic option to date. However, in the case of typical uranium ores, the  $UO_2$  content, which determines the oxygen requirement, is such that the oxygen demand of the ore is orders of magnitude smaller than that of typical sulphide ores. Consequently, the cost of oxidant is not such a dominating economic factor to uranium heap leaching, and the choice between the use of either bioleaching or the addition of chemical oxidants to effect uranium dissolution is not that obvious and needs to be investigated by a program of experimentation and economic evaluation.

## **3 Summary and Conclusions**

The following categories of heap leach applications can be identified:

- Acid soluble oxide ore
- Readily leachable sulphide ore
- Refractory sulphide ore, and
- Uranium ore

Different combinations of processing performance parameters are critical to each category, with the result that rules-of-thumb can not be applied, at least certainly not across different applications.

The acid concentration in the irrigation liquor affects several processing parameters, and the criteria according to which the irrigation acid strength is selected needs to be adapted to each type of application.

The utilisation of rest periods can serve several purposes, although an understanding of the phenomena occurring during rest periods is required to optimally apply its use to each type of heap leach application.

The use of a sulphide admixture to the ore can be considered to provide an economic source of heat and/or acid in a heap.

For the heap leaching of uranium ore, the choice between bacterial or chemical oxidation is not as clear as in the case of the heap leaching of sulphide ore, and requires experimentation and economic evaluation.

#### **4 References**

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