

FLWSHEET DEVELOPMENT FOR GOLD OREBODIES

OVERVIEW

There are several basic metallurgical flowsheets used to treat gold orebodies, with a great many permutations. The optimum flowsheet from an economic perspective is always that which achieves the greatest gold recovery at the lowest cost. Normally these two are mutually exclusive and some measure of compromise is required.

The grade of gold in the orebody can be critical in establishing the process options. Maximum gold recovery can normally be justified for high-grade deposits, even though this usually means relatively high capital and operating costs. Conversely, low-grade deposits must be treated at the lowest possible cost, even though this usually means sacrificing some gold recovery.

The lowest cost gold is normally produced by open pit mining with minimal crushing, followed by dump or heap leaching with cyanide. Gold recovery is usually around 80%, but can be as low as 60%. Recoveries can be improved to 95-99% by grinding to fairly fine particle size, gravity separation, cyanidation and flotation, all of which increase capital and operating costs.

In some cases, oxidation of sulphide minerals is needed to liberate gold that is occluded within the sulphide matrix. Sulphides can be oxidized by several methods, and the overall costs are similar.

FLWSHEET OPTIONS

CRUSHING FOLLOWED BY DUMP OR HEAP LEACHING WITH CYANIDE

This method of gold recovery is the preferred method for treating low-grade gold ores because of its low cost. Between 10-20% of the gold recovered each year from primary sources is extracted by this technique.



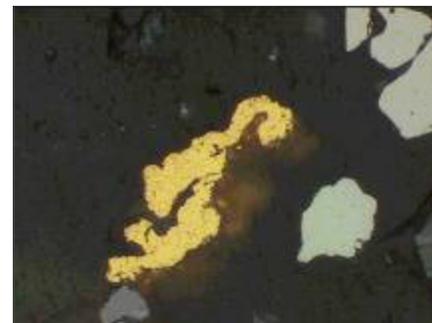
The advantages of this process are:

- Simplicity
- Favorable capital
- Favorable operating costs, which will generally be lower than the alternatives

The main disadvantage is that gold recovery is generally lower than that achieved by grinding to a finer size and leaching in stirred tanks. In addition, the rate of leaching is slow and recoverable gold can be held up in the heap for months, which impacts cash flow. There can also be longer term environmental liabilities associated with heap leaching, due to the slow release of cyanide and other toxins from abandoned heaps.

The factors that are tested to determine an ore's amenability to dump or heap leaching are:

- Its permeability, (which allows cyanide to diffuse into coarse particles)
- Its hardness or competency, (which determines the ability of individual particles or agglomerates to withstand the pressure of the mass above them without collapse).



CRUSHING AND GRINDING FOLLOWED BY GRAVITY SEPARATION

This method of gold recovery has been practised for over 4,000 years, and was the only method of separating gold from its natural environment until the late 19th century. Many modern gold plants incorporate gravity circuits as part of their overall flowsheet, and it is estimated that about 10% of the new gold produced each year is recovered by this technique.

The advantages and disadvantages of gravity separation are similar to heap leaching. It is a very simple and low cost process, but gold recovery is usually low

(0 – 50%). Therefore, gravity recovery is usually followed by additional gold recovery operations such as cyanidation and/or flotation. The amenability of a gold orebody to gravity treatment is dependent on the size and liberation characteristics of the individual gold particles in the ore. Relatively coarse gold particles that are liberated from the gangue mineral phase by crushing and grinding are readily recovered by gravity techniques, because of the large difference in specific gravity between gold (SG 19.3) and most gangue minerals (SG 2 to 3).

For gold ores that are amenable to gravity separation, recovery of the coarse, liberated gold invariably leads to lower costs and improved recovery;

- Lower costs because gravity concentrates are often of sufficiently high grade to be smelted directly to bullion without further processing
- Improved recovery because the coarse gold particles that respond well to gravity separation are slow to leach in a cyanidation circuit.

CRUSHING, GRINDING AND AGITATED TANK CYANIDATION

The cyanidation process was developed in the late 19th century and was rapidly implemented by the gold industry over the next 20 years. With its ability to leach and recover all liberated gold from the finest to the coarsest particle sizes, this process resulted in a quantum improvement in gold recovery from less than 50%, which was typical prior to the cyanidation era, to greater than 90% and often as high as 95-99%, with cyanidation. The cyanidation process accounted for 80-90% of all gold recovered by the gold mining industry from primary resources in the 20th century.

The advantages of the process are its relative simplicity, its chemical and physical durability, its relatively low cost, and the generally very high recoveries of gold (and silver), that are achieved.

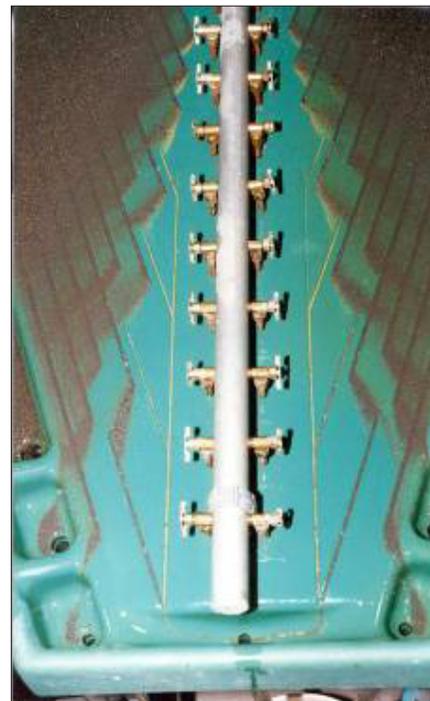
The disadvantage of the process is the toxicity of cyanide to human and animal life, and the negative perception this has

created in the public domain. Despite its toxicity, the gold mining industry has worked with cyanide for over 100 years with remarkably few human fatalities due to cyanide ingestion, and with minimal impact on the environment.

The factors that are tested to assess the amenability of an ore to the cyanidation process are gold leach efficiency and cyanide consumption as a function of the fineness of grind and other leach conditions.

REFRACTORY GOLD ORE PROCESSES

'Refractoriness' results in poor gold recovery by standard processing techniques, and can be due to either chemical or physical interference. An example of chemical interference is the presence of minerals in the orebody that consumes excessive amounts of cyanide and oxygen, the two components required for gold leaching by cyanidation. Another example of chemical interference is the presence of graphitic carbon in a gold ore. This species, which occurs naturally in many orebodies, particularly in the SW United States and West Africa, is able to re-adsorb gold cyanide from the leach solution, lowering overall gold recovery. Finally, refractoriness can be due to physical interference i.e.



the inclusion of very fine particles of gold (usually < 1 micron in diameter), in minerals that are inert and impervious to the cyanide leach liquor. Examples of such mineral phases are sulphides such as pyrite and arsenopyrite, as well as silicates.

Techniques exist for dealing with all of these situations. For example, gold that is occluded in sulphides may be



liberated by ultra-fine grinding or by oxidizing the sulphides using techniques such as roasting, pressure leaching or bacterial leaching. The adverse effect of graphitic carbon can also be overcome by roasting the ore or concentrate to burn off the carbon. All of these techniques are relatively expensive however, so the economic cut-off gold grade for refractory ores is somewhat higher than non-refractory ores.

The mining industry uses a “rule of thumb” of 80% gold recovery to define the transition from a refractory to a non-refractory gold ore. Ones under 80% are considered refractory. In assessing the economic benefit of the extra processing that must be done to improve recovery from refractory or partially refractory ores, one must consider the incremental improvement in gold recovery versus standard grinding and cyanidation, and the incremental increase in costs to achieve this improvement.

FLOTATION

Native gold and gold in sulphide minerals is readily floatable. Therefore, it is often possible to achieve high gold recovery (>90%) in a flotation concentrate. This results in a reduction of up to fifty times in the mass of gold-bearing material for further processing. This is particularly advantageous in the processing of refractory ores, since the cost of additional processing such as fine grinding or sulphide oxidation is reduced by reducing the mass of material to be treated. In some cases, the grade of gold in the concentrate is sufficiently high to ship directly to a smelter, avoiding all downstream processing costs and greatly simplifying environmental compliance.

Even in cases where standalone flotation is unable to achieve adequate gold recovery, the process can still be advantageously incorporated into an overall flowsheet, which can include standard cyanidation of the flotation tailings, combined with special treatment of the small mass of flotation concentrate.



GOLD RECOVERY AFTER CYANIDATION

Carbon Processes

The standard and preferred method of gold recovery from cyanide leachates is by adsorption onto activated carbon. For heap leach operation, gold cyanide is extracted from pregnant leach liquors onto carbon in a series of columns, by upflowing leach solution through columns that are packed with carbon. The process is known as carbon-in-columns (CIC). For mill, agitated-tank leaching operations, gold is extracted directly from the leached pulp in either a carbon-in-leach (CIL), or a carbon-in-pulp (CIP) plant. In both these cases, the coarse granules of activated carbon are mechanically mixed with the pulp in an adsorption tank, and gold-loaded carbon granules are separated from gold-depleted pulps by screening. The screening operation is done at screen mesh sizes that are intermediate between the smallest carbon granules and the largest particles of the pulp.

The basic difference between CIL and CIP is the configuration of the adsorption circuit. In a CIL plant, the carbon granules are added directly into the gold leaching tanks, so that leaching of gold (from

the ore phase to the leachate), and adsorption of gold (from the leachate to the carbon), occur simultaneously. In a CIP plant, a series of small adsorption tanks is installed after the leach plant and the leaching reaction is essentially complete before adsorption starts. CIL is advantageous when the leaching kinetics are fast and when the ore contains mineral phases that are able to re-adsorb the gold cyanide in competition with activated carbon (preg-robbing). CIP is a more efficient process for slower-leaching gold ores, and has certain other advantages over CIL, such as smaller carbon elution and regeneration circuits.

SGS has developed a carbon-in-pulp (CIP) / carbon-in-leach (CIL) modeling package to estimate the performance of a full scale commercial plant and to derive the optimum design criteria based on the results of small scale experiments.

In all three processes (CIC, CIL, CIP), carbon granules are advanced countercurrent to the direction of flow of the gold leachate. In this way, the twin objectives of simultaneously achieving high gold loading on the carbon and very low gold concentration in the final barren are attained.

Resin Processes

Anion exchange resins are also very effective adsorbents for gold cyanide, and resin processes (RIC, RIL, RIP), have been developed that are analogous to the carbon adsorption processes. In many cases, it can be demonstrated that processing of a gold ore with a resin will generate superior economic returns compared to carbon, yet the resin processes have been slow to gain acceptance by the gold mining industry. The main reason for this is the generally very satisfactory performance and robust economics that can be achieved with the well-established carbon-based processes. CIC, CIL, CIP and the analogous resin process are particularly advantageous over the alternative gold recovery processes for treating low-grade gold orebodies in large tonnage operations.

Merrill-Crowe Process

For smaller tonnage, higher-grade operations, particularly those in which the concentration of silver is greater than gold, the process that yields the most favourable economics for gold (and silver) recovery is Merrill Crowe cementation. In this process, the leachate is separated from the barren, leached ore, and gold and silver is precipitated from the pregnant liquor by reduction (cementation) on fine zinc powder. For very high grade solutions (> 20 mg/L Au + Ag), the process that produces the best economics in most cases is direct electrowinning of the precious metals from the pregnant leach

liquors. In such cases, the water balance in the plant will require the incorporation of a hybrid process including both direct electrowinning of high-grade solution and carbon adsorption of low-grade waste or bleed streams.

SGS Minerals Services has very extensive experience with all the unit operations involved in the processing of gold ores, and in selecting the optimum flowsheet for a particular ore.

ENVIRONMENTAL COMPLIANCE

An important factor that must be taken into consideration in flowsheet selection and economic evaluation of a gold project is the cost of environmental compliance. This can be significant, and varies with the flowsheet and also from country to country.

Cyanide must be destroyed prior to discharge to a tailings pond in most jurisdictions, and must always be destroyed prior to discharge to the natural environment. The cost of cyanide destruction depends on the specific method selected and the limits imposed by local regulations. In turn this depends not only on the concentration of cyanide in the effluent, but also the concentrations of metal cyanide complexes and many other soluble species.

CONTACT INFORMATION

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