INTRODUCTION TO EVALUATION, DESIGN AND OPERATION OF PRECIOUS METAL HEAP LEACHING PROJECTS

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Chapter 5

Ore Preparation: Crushing and Agglomeration

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5.1 INTRODUCTION

Heap leach cyanidation techniques possess considerable potential for exploitation of low-grade ores, small ore bodies, mine strip waste and tailing materials where fine grinding is not necessary for good extraction. For heap leaching to be successful, ore must exhibit certain characteristics, as previously discussed in Chapter 1. Primary among the necessary ore characteristics is that the ore must have good permeability after being crushed or treated and stacked into heaps if uniform distribution of the cyanide leach solution is to be achieved.

Gold and silver ores containing excessive amounts of clays or fines generated by crushing are some of the most difficult to treat successfully by heap leaching. The presence of excessive amounts of slimes (generally classified as minus 50-micron or 270 Tyler mesh sieve size particles) in the heap leach feed will slow the percolation flow of the leach solution, cause channeling, or produce dormant or unleached areas within the heap. This may result in unreasonably long leaching periods and poor extractions. In extreme cases, the clays or slimes can completely seal the ore heap, causing the leach solution to run off the sides of the heap rather than to penetrate the ore heap.

The problem of heap leaching ores containing fines can be aggravated during stacking and preparation of the ore heaps, because natural sorting of coarse and fine material occurs during these steps (Johanson, 1978). This phenomenon results in a concentration of ore fines at the center of individual ore piles and a concomitant concentration of larger rock fragments on the lower slopes and base of the piles. When the individual piles within the heap are leveled off prior to installation of the sprinkling system which delivers the leach solution, additional segregation occurs as the fines sift through the coarser ore particles. The segregation results in localized areas or zones with marked differences in permeability. As a consequence, the leach solutions follow the path of least resistance, percolating downward through the coarse ore regions and bypassing or barely wetting areas that contain large amounts of fines or slimes. Effective utilization of marginal gold and silver resources through heap leach processing requires the development of new methods in order to achieve more uniform size distribution during ore heap preparation and better slime control during leaching.
As briefly discussed in the preceding chapter, agglomeration pretreatment has been shown to be effective for the exploitation of low-grade materials which display poor percolation characteristics. In some cases, agglomeration-heaip leaching is the only viable processing technique for a problem feed. However, crushing circuits and agglomerating systems are capital intensive, and should not be incorporated into a commercial operation unless absolutely necessary. Careful attention should be given to determining the requirement for agglomeration pretreatment for a particular feed before committing it to the commercial operation. This chapter provides some guidelines for the effective and economic use of agglomeration systems, as well as a brief history of the development of agglomeration technology.

Agglomeration and balling of crushed ore to produce a porous and more uniform feed material for heap leaching is a viable method for treating clayey ores. In the mid-1970's the U.S. Bureau of Mines (USBM) in Reno, Nevada, began an agglomeration pretreatment research program to allow the commercial exploitation of these poorly percolating feed materials. Prior to this, little attention had been given to such methods for improving uniform percolation flow of leach solutions through silver and gold ores. However, the general idea of ore agglomeration was advanced and, to some extent, researched well before the USBM research program.

In 1905, T.C. Scrutton developed a unique technique for obtaining rapid vat leaching of a clayey ore in which the gold was finely disseminated (Dorr and Bosqui, 1950). Scrutton's technique consisted of rolling the ore down a chute inclined at 60 degrees to form agglomerates or balls readily permeable to the cyanide solution. However, these agglomerates lacked rigidity and, to ensure good percolation leaching and washing, they could not be bedded in layers more than three ft deep. If this depth was exceeded, difficulties would be experienced in obtaining uniform leaching and washing, resulting in reduced gold recovery. Shepard and Skinner (1937), studied the addition of lime and carbon dioxide or calcium carbonate to gold-bearing tailings to form agglomerates suitable for vat leaching. Satisfactory percolation flow rates were achieved in 90-gram scale experiments, but the reagent requirements were prohibitive.

Agglomeration and pelletizing have been used in other segments of the mineral industry. This technique was first used successfully around 1911 for pelletizing iron ores (Davis and Wade, 1951; English and Frans, 1977). Since that time, agglomeration and pelletizing (or briquetting) have been widely adopted for consolidation of fines for many other materials such as manganese, fluor spar, and phosphates. These materials have been pelletized to consolidate fine particles into large, dense, and mechanically strong masses, principally to prevent dusting problems during furnacing operations.

The objective of the USBM's investigations in the 1970's was to evaluate particle agglomeration procedures for improving flow rates in the heap leach cyanidation process. The concept was to investigate procedures whereby loose-knit, polymerlike agglomerates could be formed that were highly permeable to solution flow and yet mechanically stable during the leaching sequence.

Three important agglomeration parameters were determined from the USBM's work for successful agglomeration pretreatment of crushed ores with poor percolation characteristics. The parameters were: 1) quantity of binder
(portland cement) added to the dry feed; 2) amount of moisture added to the binder/ore mixture; and 3) the curing period required to form calcium silicate bridging. The investigation revealed that most crushed ores (finer than 1 inch) could be effectively agglomerated by mixing 10 lbs of portland cement per ton (5 kg/mt) of dry feed, wetting with water or cyanide solution to a final moisture content of about 12 weight percent, mechanically tumbling the wetted mixture to effect agglomeration, and curing for more than eight hours before applying conventional heap leaching techniques (Heinen, et al., 1979; McClelland and Eisele, 1982).

The agglomeration technology developed by the USBM was rapidly adopted by the precious metal production industry. The first pilot-scale column percolation leaching tests on agglomerated feeds were performed in 1978. The initial pilot-scale heap leach test on crushed and agglomerated ore was conducted in eastern Nevada in 1979. The first commercial agglomeration-heap leach operation poured bullion in late 1980. Many operators have since adopted the technology for producing precious metals from their low-grade ore deposits, mine wastes, and milled tailings materials.

5.2 AGGLOMERATION PRINCIPLES

The basic objective of agglomerating precious metal ores for heap leaching is to produce porous ore which will be stable when handled, stacked, and percolated with lixiviant. As previously discussed, excessive fines in an ore can lead to reduction in heap permeability, as well as increased channeling, and blinding.

A somewhat similar application of the general principle of agglomeration is in the proven procedure of soil stabilization for road construction (i.e., the mixing of road pavement materials with stabilizing agents to improve their strength and construction behavior). Cement, lime, fly-ash, asphalt, and other chemicals (e.g., calcium silicate) have been used for stabilization. Amounts used in road construction usually range from 5 to 10 percent by weight. It is clear that such high percentages of additives are not economical for heap leach purposes. Optimization is therefore important.

With regard to ore agglomeration, similar materials to those used in road construction work (i.e., cement and fly-ash) have been used with some success. All of these binders have in common two important physical/chemical effects which account in large part for the success with which they have been used:

- The exchange of sodium cations in the ore clay particles with calcium cations from the binder, thereby improving the workability and permeability of clay materials; and
- The cementing (or pozzolanic) action of binder, thereby adding strength to the agglomerated materials.

It should be noted here that the different binders may vary in effectiveness, depending on the ore in question and the particular needs of each agglomerating system. For example, lime is very effective in obtaining the sodium cation exchange reaction; however, the strength obtained from lime and the rate at which strength increases are both lower for lime than for cement and some types of fly-ash. Depending on the ore type, the cation
exchange reaction may or may not be more important than strength and rate of reaction. It is, therefore, important to carefully investigate the behavior of ore with respect to binder.

Two basic pathways for successful agglomeration can be identified for precious metal ores. These are:

- Agglomeration of fines onto coarse crushed ore and waste; and
- Agglomeration of fines into stable balls.

Figure 5.1 shows schematics of the agglomeration effects. In the latter instance (fines agglomerating into stable balls) the fines can be silt and sand particles or they can contain high percentages of clay (examples b and c on Figure 5.1). Moderate to moderately high quantities of binder are required for the agglomeration of fines and tailings into stable balls. Specific projects exemplifying this type of agglomeration are discussed in Subchapters 5.6 through 5.8.

When fine material such as tailings with no or little clay is agglomerated, the fines are bound together with a binder such as portland cement. Clayey ore is particularly difficult to leach effectively because of the low permeability of clay. Bentonitic clays (sodium montmorillonite) are especially a problem. In the general Civil Engineering industry, such clays have been "stabilized" (i.e., workability and permeability have been increased), successfully using lime. Cation exchange takes place and the sodium rich clay changes to a calcium rich clay. It is, therefore, suggested that clayey ores can be agglomerated by using lime and portland cement as binders. The lime will "stabilize" the clay minerals, while the portland cement will form a strong binder. In order to "stabilize" the clay effectively, the lime must come in close contact with the clay minerals.

In the case of agglomeration of crushed ore and wastes containing high percentages of fines, the fines are bound to the coarse particles (see example a on Figure 5.1). Typically, portland cement can be used as a binder and low to moderately low quantities are sufficient. Subchapter 5.6 discusses specific projects which are examples of this type of agglomeration.

### 5.3 AGGLOMERATORS

This subchapter discusses agglomeration design factors and then goes on to describe the various kinds of agglomerators which have been successfully used on precious metal ores. Agglomeration design factors include (Milligan, 1983):

- Feed characteristics, e.g. particle size and presence of fractures in particles. The relationship between $t$, the time to a given extraction and $D$, the particle diameter, can be stated as:

$$ t = C_1 D^2; $$

where $C_1$ is a constant. For rapid uniform high precious metal recovery, the finest crush is therefore desirable. Fine grinding is in conflict with the uniformly high permeability requirements of heap leaching. Agglomeration makes these two more compatible;
**BEFORE AGGLOMERATION**

a) COARSE MATERIAL WITH LARGE PERCENTAGE FINES.

b) FINE MATERIAL, e.g. TAILINGS WITH NO OR LITTLE CLAY

c) CLAY MATERIAL WITH METAL "LOCKED" IN LOW PERMEABILITY MEDIUM.

**AFTER AGGLOMERATION**

a) FINES ARE AGGLOMERATED ONTO COARSE PARTICLES, BINDER SUCH AS PORTLAND CEMENT IS USED.

b) AGGLOMERATES ARE FORMED BY BINDING FINES TOGETHER WITH BINDER SUCH AS PORTLAND CEMENT.

c) AGGLOMERATES ARE FORMED BY BINDING FINES TOGETHER AFTER MODIFYING CLAY PROPERTIES, LIME AND PORTLAND CEMENT CAN BE USED.

**FIGURE 5.1**

AGGLOMERATION EFFECTS
- Process control, e.g. feed rate and type of ore and binder addition rates. Optimum conditions are obtained during steady-state conditions of optimum feed size and rate and at optimum moisture and binder addition rates (as discussed below). Operator control is very important and continuous monitoring may be required if upsets are frequent; and

- Equipment selection. The agglomerator must provide the agitation and motion needed to make the necessary green strength for construction of the heap. The three major types of agglomerators for gold and silver ores are belt, drum and pan. These three are discussed below. The discussion is taken from Milligan (1983). Other methods of agglomeration include stockpile agglomeration, vibrating deck, and steeply inclined conveyor belts (Chamberlain, 1986).

5.3.1 Belt Agglomerators

Belt-type agglomerators use conveyors to obtain the necessary tumbling and compaction. This agglomerator type produces the least degree of compaction and agglomeration of any agglomerator currently in use. The belt may be steeply inclined to induce rolling on the belt or may have multiple transfer points at which agitation and compaction occur. The higher the percentage of fines, the more transfer points are needed (hard siliceous ore with five percent - 100 mesh, two to three transfers, and with 10 percent or 15 percent - 100 mesh, four to five transfers) (Chamberlain, 1986). Agglomeration may also be induced during discharge where the ore rolls down a steep incline. Figure 5.2, Belt Agglomerator Sizing, illustrates the capacity of a typical three-drop conveyor agglomeration. Sizing is based on the carrying capacity of the belt near the maximum speed. Figure 5.3, Belt Agglomerator Cost, illustrates an estimated budget comparison cost of such an agglomerator.

This type of agglomerator is suitable where the ore contains very little fine material and a coarse crush yields good precious metal extraction.

5.3.2 Drum Agglomerators

The drum-type agglomerator uses a drum to obtain the required tumbling and compaction for agglomeration. This type of equipment produces a fairly wide size distribution of agglomerates. The green strength can be excellent depending on equipment size and production rate. Figure 5.4, Drum Agglomeration Sizing, illustrates a typical rating capacity for drum agglomerators. The following equation can also be used to determine residence time in an agglomerator. Rate of growth of agglomerate reaches a maximum at the optimum moisture content:

\[ T = \frac{1.77 \sqrt{A L}}{S D N} \]

where \( T \) is required residence time (minutes), \( A \) is the angle of repose of material (degrees), \( S \) is the slope of shell (degrees), \( N \) is speed of drum (rpm), \( L \) is length of drum (ft), and \( D \) is diameter of drum (ft). Agglomerate size and strength increases with longer residence time (revolutions).
FIGURE 5.2

BELT AGGLOMERATOR SIZING
(from Milligan, 1983)
FIGURE 5.3
BELT AGGLOMERATOR COST
(from Milligan, 1983)
FIGURE 5.4

DRUM AGGLOMERATOR SIZING
(from Milligan, 1983)
Typically for scale-up, the L to D ratio is kept constant (between 2 and 4), the slope of the shell is constant near 7 degrees, and the residence time remains constant as does the degree of loading. Figure 5.5, Drum Agglomerator Cost, illustrates the typical budget cost of drum agglomerators.

Recent improvement in the drum agglomerator includes the use of flexible rubber liners to reduce caking within the drum and to eliminate large oversize material.

5.3.3 Pan Agglomerators

The pan-type (disk) agglomerator uses a flat inclined pan to obtain the required tumbling and compaction. This equipment produces a uniform agglomerate with excellent green strength. Figure 5.6, Pan Agglomerator Sizing, illustrates a typical rating for pan agglomeration. The following equation can also be used to scale up design:

\[
\frac{C}{D^{2.58}} = \text{Constant;}
\]

where C is capacity and D is diameter of a shallow disk or pan.

The major operating parameters in the pan agglomerator are: 1) angle of disk; 2) speed of disk; 3) point of material feed; and 4) location and amount of water spray. If the water is sprayed upon the larger agglomerate, the agglomerate will tend to increase in size. If the feed material and the water spray location are on or near fine material, the agglomerate will tend to be small. Larger pellets are formed if the feed and spray are brought closer together. Budget costs of this type of equipment are illustrated in Figure 5.7, Pan Agglomerator Cost.

Table 5.1 is a partial list of suppliers for both drum and pan agglomerators. Most have their own testing facilities. Belt agglomerators are innovations by operators and as such are not available as predesigned units.

5.4 OPTIMUM WATER CONTENT FOR AGGLOMERATION

The proper moisture content for agglomeration is determined by the particle size, clay content, wetting characteristics, and desired degree of compaction during agglomeration. The mass must not be saturated, however, for this destroys the green strength. Green strength is a term applied to the strength of agglomerates to stand up to processing and handling. A sufficient green strength is required to resist crushing during heap building. Green strength is made up of strength imparted by a binder, but mostly due to the tension of the water menisci.

A simple method of estimating the proper moisture content for agglomeration is to mix a slurry of the ore in water and filter on a vacuum filter. The dewatered filter cake will contain slightly more water than necessary for proper agglomeration.

Another technique for estimating the proper moisture content is to obtain the water content vs. dry density relationship for the soil by using a Standard Proctor Compaction test. The optimum moisture content is a good estimate for the proper agglomeration moisture content.
FIGURE 5.5
DRUM AGGLOMERATOR COST
(from Milligan, 1983)
FIGURE 5.6
PAN AGGLOMERATOR COST
(from Milligan, 1983)
FIGURE 5.7
PAN AGGLOMERATOR SIZING
(from Milligan, 1983)
TABLE 5.1
AGGLOMERATOR SUPPLIERS

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Address</th>
<th>Contact Name</th>
<th>Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acme International Ltd.</td>
<td>Attn. Richard Stollman 100 T.S. West Ave.</td>
<td></td>
<td>215-885-7750</td>
</tr>
<tr>
<td>Allis-Chalmers Mining Systems Div.</td>
<td>Attn. George Skoronski Box 512 Milwaukee, WI 53201</td>
<td></td>
<td>414-475-2437</td>
</tr>
<tr>
<td>Bepex Corp.</td>
<td>Attn. Dave Phillips Minneapolis, MN 612-331-4370</td>
<td></td>
<td></td>
</tr>
<tr>
<td>California Pellet Mill Co.</td>
<td>1800 Folsom St. San Francisco, CA 94103</td>
<td></td>
<td>415-431-3800</td>
</tr>
<tr>
<td>Dravo Company</td>
<td>Attn. D.W. Kestner One Oliver Plaza Pittsburg, PA 15222</td>
<td></td>
<td>412-566-3000</td>
</tr>
<tr>
<td>Feeco International Inc.</td>
<td>Attn. Larry Cliver 3913 Algoma Rd. Dept. A Green Bay, WI 54301</td>
<td></td>
<td>414-468-1000</td>
</tr>
<tr>
<td>Ferro-Tech</td>
<td>Attn. Carl Holly Eureka and 5 Ave. (467 Eureka Rd.) Wyandotte, MI 48192</td>
<td></td>
<td>313-282-7300</td>
</tr>
<tr>
<td>Glatt Air Technique</td>
<td>Attn. Steve Abbely 20-T Spear Rdt. Ramsey, NJ</td>
<td></td>
<td>201-825-8700</td>
</tr>
<tr>
<td>Legend Metallurgical Laboratory</td>
<td>Attn. Larry 125-T Manuel St. Reno, NV 89502</td>
<td></td>
<td>702-786-3003</td>
</tr>
<tr>
<td>O'Brien Industrial Equipment Co.</td>
<td>Attn. Andy Whitaker 1596 Hudson Avenue at Newhall San Francisco, CA</td>
<td></td>
<td>415-826-3033</td>
</tr>
</tbody>
</table>
5.5 AGGLOMERATION OF CRUSHED ORES AND WASTES

Most precious metal ores and wastes require crushing to minus one inch (25 mm) or finer before agglomeration. Crushing to these sizes liberates precious metal values and improves overall recovery. Crushing to about 3/4 inch (19 mm) usually requires two stages of crushing. A feed size of about 3/8 inch (9 mm) is considered the economic minimum, and requires three crushing stages. Primary crushing is usually accomplished by a jaw or a standard cone crusher. Secondary and tertiary crushing is usually done using short-head cone crushers.

Crushed ores can, in general, be agglomerated by mixing 5 to 10 lbs of portland cement per ton (2.5 to 5 kg/per ton) of dry feed, wetting with 8 to 16 percent moisture as either water or strong cyanide solution, mechanically tumbling the wetted mixture, and curing the agglomerated feed during heap building procedures. The quantity of cement added during agglomeration usually provides the protective alkalinity required for cyanide leaching. After agglomeration and heap building, leaching is conducted with conventional heap leaching techniques.

During agglomeration, the clay and fine particles contained in the ore adhere to the coarser particles and create a coating of fines around the coarse particles. The agglomerates produced are of sufficient green strength after curing to withstand handling and wetting with minimal degradation. Agglomeration overcomes the major problems associated with particle segregation during heap building, fines migration, and solution channeling during leaching by producing a porous, permeable feed.

A permeable feed material stacked in a heap permits the uniform flow of leaching solution and contact of the cyanide leaching solution with the exposed precious metal particles, and decreases the leaching time required to obtain targeted precious metal recovery.

The following is a brief description of one conventional heap leach operation (no agglomeration) and three commercial operations where crushing and agglomeration pretreatment was necessary for the successful heap leaching treatment of the ore. The three were selected for discussion because of the diversity of the agglomerating equipment used for pretreating the ore. Two of the operations have been producing bullion since the early 1980's and the information given herein describes their operation shortly after start-up. The third operation began production in early 1985. All three are considered moderate sized heap leaching operations and their production rates range from 2,000 to 3,500 tons of ore per day.

5.6 EXAMPLES OF CRUSHED ORE AGGLOMERATION

5.6.1 Central Nevada Gold Conventional Heap Leach: 20,000 Tons Per Day

A conventional gold heap leaching operation is located near the geographical center of the state of Nevada. The siliceous ore is mined at a rate of about 20,000 tons per day (TPD) using open-pit mining methods. Mined ore is trucked to an in-pit underground primary standard cone crusher. Discharge from the primary crusher (approximately four inches, 100 mm) is conveyed to a secondary short head cone crusher where it is reduced in size to nominal minus one inch. The secondary crushed feed is conveyed a short
distance to two short head cone crushers and is reduced to an 80 percent passing 3/8 inch (9 mm) feed size.

The ore is very siliceous and few fines are generated by crushing to 3/8 inch (9 mm). Consequently, agglomeration pretreatment is not necessary for controlling fines migration during leaching. Gold grade averages 0.045 ounces per ton (1.5 g/mt), and some visible gold is present in the feed.

Crushed ore is conveyed to an underground ore stockpile. Lime is added to the ore at the conveyor before it reaches the ore stockpile. The ore-lime mixture is conveyed from the stockpile to a truck load out bin and is transported to the asphalt pad by truck. Heaps are built to a height of 40 ft (12 m) by pushing up the angle of repose with a tracked dozer. Overall dimensions of the heap are 4,800 ft x 300 ft x 40 ft (1,460 m x 91 m x 12 m). This size heap will allow for the continuous leaching of 1.2 million tons of ore.

Leaching is conducted by applying cyanide solution containing 1.0 lbs NaCN per ton (0.5 kg/mt) of solution over the heaps at a rate of 0.005 gpm/ft² (0.003 l/s/m²) of heap surface area. Wobbler sprinklers are used for applying solution in a pattern to ensure maximum coverage and minimum evaporation. A 52 to 55 day leach cycle is required to obtain targeted gold recovery. Leached ore is removed from the leach pad and is trucked a short distance to the tailings disposal area.

Pregnant solution drains from the heap and flows by gravity to collection ditches. Solution in the ditches flow by gravity to a pregnant solution reservoir and is pumped through a five-stage carbon adsorption circuit at a rate of 2,600 gpm (164 l/s). The carbon adsorption circuit contains from 15 to 18 tons of carbon. A total of 2.7 volume tons of carbon is desorbed in about eight hours using pressure stripping technology. Desorbed carbon is acid washed and thermally regenerated before being recycled to the adsorption circuit. Gold values stripped from the carbon are electrowon onto steel wool cathodes. Cathodes are refined onsite to produce dore bullion. Dore bullion is about 92 percent gold, and is shipped to a custom refinery for purification.

Low-grade ore from the mine is dump leached at a run-of-mine feed size. About 600,000 tons of low-grade is leached at a time on a clay pad. The dump leach site has its own carbon adsorption circuit, but loaded carbon is processed at the mine plant site. Barren solution from the carbon circuit is recycled to the dump. Multiple lifts of low-grade ore will ultimately be processed on the clay pad. Each lift is 60 ft (18 m) in height. Lifts are built by truck dumping from the surface of the dump.

Few problems are experienced with heap leaching in this operation, primarily because the ore is very "clean" and contains almost no cyanicides. It is reported that the key to the success of this operation is the efficient stripping and reactivation of the carbon. The operation is in the process of expansion to 40,000 TPD of crushed feed.

5.6.2 Arizona Silver Heap Leaching: 2,000 Tons Per Day

A silver agglomeration-heap leaching operation is located near Tombstone, Arizona (Anon, 1981; McClelland, et al., 1983). Two types of
materials are mined: old waste material which was used for mine backfill; and
virgin ore adjacent to the waste material. The waste material is mined with
front-end loaders to expose the virgin ore. The virgin ore is drilled and
blasted and moved by front-end loaders. The silver content of the two feed
materials varies. The cutoff grade of feed to the heaps is 1.0 troy ounce of
silver per ton (about 34 g/mt). Approximately 2,000 tons per day of ore are
mined and agglomerated.

The mined ore and mineralized waste are moved from a stockpile to the
crushing plant where they are crushed to a nominal 1/2 inch (12 mm) with three
stages of crushing and screening. Run-of-mine ore is fed to the primary jaw
and is discharged at about a 2-1/2 inch (37 mm) size. Secondary and tertiary
crushing is done with a screening circuit and short head cone crushing system.
Lime (7 lbs, 3 kg, per ton of ore) is used as the binder for agglomeration and
is mixed with the ore during secondary crushing. The crushed ore-lime mixture
is conveyed to an underground ore stockpile. Some moisture is sprayed onto the
ore on the crusher discharge conveyor to decrease dusting.

The ore from the underground stockpile is agglomerated on a reverse belt
conveyor designed by the operators. The 4 ft (1.2 m) x 25 ft (7.6 m) belt
agglomerates ore at a rate of 200 tons per hour. The agglomerating conveyor
can be set at an angle between 35° and 45°, and the belt travels upward while
the ore moves down the belt. The angle and speed of the belt can be varied to
provide the desired retention time of ore on the belt. Water is sprayed at
several locations along the length of the belt and gives the agglomerated feed
a moisture content of between 10 and 12 percent. A small amount of moistened
fines adheres to the belt and rides up the conveyor. A scraper at the bottom
side of the drive roller eliminates excessive fines build-up.

The agglomerated ore is transported to a stockpile by a radial arm
stacker. The material from the stockpile is trucked 500 ft (150 m) to a 3/4
acre (4,000 m²) leaching pad and is allowed to cure during heap building. Five
heaps, each containing 6,000 tons of agglomerated ore stacked 10 to 11 ft (3
to 3.4 m) high, are leached on the pad. Three heaps are at different stages of
leaching, while the other two are either being prepared for leaching or being
removed from the pad.

The heaps are sprayed with pH 10.5 solution containing two lbs NaCN per
ton (1 kg/mt) at a rate of 0.0075 gpm/ft² (0.005 l/s/m²). The leaching
solution percolates through the heap, is collected on the impervious leaching
pad, and drains into the plastic-lined solution trenches. The leaching and
washing cycle is seven days. The leached residue is transferred to an
auxiliary leaching pad and sprayed with cyanide solution one day per month for
additional precious metal extraction. Precious metal values in the pregnant
solution are recovered by Merrill-Crowe zinc precipitation technology. The
precious-metal-bearing zinc precipitates are refined on site and yield dore
bullion. The dore is shipped to another facility for refining. The barren
solutions are recycled to the heaps.

Heap leaching was unsuccessful before agglomeration pretreatment was
applied to the ore. Conventional heap leaching recovered only 37 percent of
the leachable silver from three inch (75 mm) feed material treated in 90 day
leaching cycles. Severe percolation problems were encountered. Agglomeration
permitted finer crushing, which liberated additional silver values for
ORE PREPARATION: CRUSHING AND AGGLOMERATION

5.6.3 Northern Nevada Gold Heap Leaching: 2,500 Tons Per Day

An operation in northern Nevada, which has produced gold by agitation cyanidation and countercurrent decantation for several years, discovered a new ore deposit several miles from the working mine. Higher grade ore from the new deposit is transported to the original mill for gold recovery. Ore containing less than 0.07 troy ounce gold per ton (2.4 g/mt) is heap leached at the new site. Average ore grade for the heap material is 0.034 troy ounce gold per ton (1.2 g/mt). The ore is mined by open-pit methods and is trucked to the heap leaching site approximately one-half mile (0.8 km) from the new pit. About 2,500 tons per day of ore are mined and heap leached.

The ore is crushed to minus 5/8 inch (16 mm) by a primary jaw crusher and a secondary cone crusher. Portland cement (type II), at the rate of 7 to 10 lbs per ton (3.5 to 5 kg/mt) of ore, is added to the ore at the primary jaw crusher discharge conveyor, and is mixed with the ore during secondary crushing. The ore-binder mixture from secondary crushing is conveyed to a radial arm stacker. Water is sprayed onto the mixture at the discharge end of the stacker and results in a final moisture content of 9 to 13 percent. The ore is agglomerated by cascading down the sides of the conically-shaped agglomerated ore stockpile. Additional tumbling, sufficient to effect agglomeration, occurs when the front-end loader loads the rear dump truck with agglomerates from the stock pile and when the truck dumps the agglomerated feed onto the asphalt leaching pad. The agglomerated ore is cured for two to three days while the heap is being built.

Five 17,000-ton heaps, approximately 12 ft (3.7 m) high, are built on the leaching pad. Three heaps are in different stages of the leaching cycle while the remaining two are either being prepared for leaching or being removed from the pad.

The agglomerated heaps are leached by spraying 0.004 to 0.005 gpm/ft² (about 0.003 l/s/m²) of pH 10-11 solution containing 1.0 lb NaCN per ton (0.5 kg/mt) of solution. The portland cement added during agglomeration provides most of the alkalinity required during leaching, but small quantities of NaOH are added to the barren solution to maintain the desired pH value. The leaching and washing cycle is 20 days. Leached residues are transported to a tailings disposal area.

The pregnant solution draining from the leaching pad flows by gravity to a reservoir and is pumped through a series of five carbon adsorption tanks for recovery of dissolved gold values. The gold-loaded, 12 x 30 mesh, coconut shell activated carbon is transported to the original mill site for desorption by an alkaline alcohol solution. The values desorbed from the carbon are electrowon on steel wool cathodes, which are refined on site to produce dore bullion.

This operation initially tried conventional heap leaching to process the low-grade ore. Conventional heap leaching was unsuccessful because of the high clay content of the ore, particle segregation, and fines migration, which resulted in leach solution channeling. Agglomeration pretreatment increased
gold recovery by 60 percent, while decreasing the leaching cycle from 50 days to 20 days. Even with agglomeration, some ore retains approximately 30 percent moisture, and long washing periods are required to recover the dissolved values from the agglomerates. The longer washing cycle extends the total leaching cycle to 30 days for some heaps.

5.6.4 West Central Nevada Gold Heap Leach: 3,500 Tons Per Day

An operation in west central Nevada processes 3,500 TPD of crushed and agglomerated gold ore. Ore is mined using open-pit methods. Drilled and blasted ore is loaded by a front-end loader onto trucks and is hauled about 0.5 miles (0.8 km) to the crushing circuit. A primary jaw crusher produces a minus six inch (150 mm) feed. The primary crusher discharge is conveyed a short distance to a secondary short head cone crusher where it is reduced in size to a nominal minus one inch.

The crushed ore is very clayey and contains about 25 weight percent minus 100 mesh fines. The crushed ore is agglomerated by adding 10 lbs portland cement per ton (5 kg/mt) to the secondary crusher. Wetting at several locations with barren solution containing cyanide to a final moisture content of 10 to 12 weight percent, mechanically tumbling in a three-stage drop belt agglomeration circuit, and curing in a stockpile for three to four days before being placed on the pad.

Leaching is conducted on the primary heaps by applying cyanide solution containing 0.2 lbs NaCN per ton (0.1 kg/mt) of solution at a rate of 0.003 gpm per sq ft (0.002 l/s/m²) of heap surface area. Primary heaps are constructed on asphalt pads to a height of 12 ft (3.7 m) by lifting with a front-end loader. A total of five heaps are processed at once. Three heaps are in different stages of leaching while one is being removed from the pad, and the other is being built. A 21-day leaching and washing cycle is required for each primary heap to achieve 75 percent gold recovery.

Leached residue from the primary heaps is trucked to the releach pad area. Releach heaps are built by truck dusting from the heap surface to a height of 100 to 120 ft (30 to 37 m). Several months of releaching is required to increase the overall gold recovery from the crushed ore to 85 percent.

Low-grade ore from the mine is processed by dump leaching at a run-of-mine feed size. Dumps are built on clay pads to a height of 120 ft by truck dumping from the heap surface. Low-grade ore remains on the pad until it becomes uneconomical to process and recycle solutions. Dump leach cycles usually are from 9 to 14 months.

Each type of heap (primary, releach and dump) has its own pregnant solution reservoirs. All pregnant solutions ultimately are processed in a single zinc precipitation circuit. Solutions from any of the pregnant ponds can be taken directly to the zinc circuit or can be diverted to other heaps to increase pregnant solution gold concentrations. Pregnant solutions drain by gravity to a surge tank for processing through the zinc circuit. Solutions are clarified and deaerated before adding the Merrillite zinc dust. The zinc circuit can process 600 gpm (37.8 l/s) of pregnant solution. Precipitates are recovered in filter presses and are refined onsite to produce dore bullion.
A total of 2,000 gpm (126 l/s) of pregnant solution drains from the various heaps. The zinc precipitation circuit can process only 600 gpm (37.8 l/s). Consequently, it is difficult to obtain a good solution balance for the operation. Even though solutions can be diverted from any heap at a specific solution grade, it is still difficult to obtain a solution balance from any given heap because all solutions are processed through a single zinc circuit.

The operation does not have to shut down during the winter months because barren solutions are heated to 30°F. Solutions are heated with a heat exchanger circuit.

Some problems are inherent to this operation. Organic compounds contained in the ore caused problems in the zinc precipitation circuit. Most severe precipitation problems were encountered early in the project. Gold precipitation problems were minimized by precipitating the dissolved organics with barium chloride. Scaling has been a major problem the duration of the project. Scaling has been controlled by the use of descaler chemicals. In severe cases, lines have to be physically unplugged using a hydrojet. Solution balance remains the major problem. This problem can only be solved by increasing the capacity of the zinc circuit or by building separate solution recovery systems for the releach and dump heap leach circuits. The operation has been very successful even with the problems encountered.

5.7 AGGLOMERATION OF FINELY GROUND TAILINGS

The Western United States has many tailings materials from former mining operations that contain significant precious metal values. Most of these tailings resources are too low-grade or too small to warrant the capital expenditure to construct a conventional agitated cyanide leaching circuit (McClelland, et al., 1985). In most cases, the only viable processing technology for these feeds is agglomeration-heap leaching.

Agglomerating parameters which are important for successful treatment of crushed ores are equally important for tailings agglomeration with some modification. The binder normally required for tailings agglomeration is a combination of lime and cement, usually 10 - 15 lbs of each per ton of dry feed. Moisture additions are usually higher, at from 16 to 22 weight percent final moisture. Curing times in the range of 72 hours or longer are required. Two mechanical parameters are also important for agglomerating tailings:

- Moisture should be added as a non-atomizing spray or as droplets; and
- A rolling, rather than a bouncing or tumbling, action should be imparted to the tailings by the agglomerator.

Solution should be added as droplets or coarse spray because the water drop impacting the dry feed immediately forms a small ball which acts as the nucleus for agglomerate growth. If fine sprays are used, no nucleus is formed.

Agglomerators such as drums, disks, and pug mills impart a rolling rather than a bouncing (belts) action to the tailings being agglomerated. These types of agglomerators are required for effective tailings agglomeration.
Several commercial-scale tailings agglomeration-heap leach operations have been successful. Three successful operations are briefly described below. The operations, however, are not in current production. The gold tailings projects were completed and all the tailings were leached. The silver tailings project was shut down because of the low silver price (less than $7.00 per ounce). None of the tailings feed materials could be economically processed by means other than agglomeration-heap leaching.

5.8 EXAMPLES OF TAILINGS AGGLOMERATION

5.8.1 Gold Agglomeration-Heap Leaching in South-Central Nevada

A tailings material from the south-central Nevada Goldfield District was processed by agglomeration pretreatment and heap leach cyanidation. The tailings resulted from a cyanide milling operation that was active just after the turn of the century. The original ore was high in sulfides and gold recoveries were low. The tailings oxidized for approximately 70 years by natural weathering and residual sulfides oxidized to soluble sulfate. The natural pH of a 50 percent solids slurry was 1.7 because of the soluble sulfates. The tailings were 65 percent minus 200 mesh (0.074 mm) and contained 0.08 ounce Au per ton (2.7 g/mt) of tailings. The maximum gold recovery by agitated cyanidation was 83 percent.

The tailings were moved to the agglomerating plant by a front-end loader and dumped into a hopper. The tailings were conveyed to a 8.5 ft (2.6 m) x 22 ft (6.7 m) drum agglomerator, which was a modified asphalt kiln. The drum rotated at 10.5 rpm, had a slope to the discharge end of 4 degrees and was lined with loosely fitting conveyor belt material. A spray bar was situated lengthwise in the drum and delivered a fan droplet spray that covered three-fourths of the length of the drum. A lime-cement slurry was applied through the spray system to add binder and bring the final moisture content of the agglomerates to between 12 and 14 weight percent. The total binder addition was 50 lbs (25 kg) lime and 10 lbs (5 kg) cement per ton (mt) of dry feed. The large lime addition was required to adjust the pH of the tailings from 1.7 to 10.5. A 12 inch (30 cm) weir on the inside of the drum was four ft from the discharge end to increase feed retention time and to prevent discharge surging. The agglomerates discharged from the drum to a transfer point feeding a radial arm stacker. The green agglomerates were gently placed on the heap by the stacker and cured during heap building.

The leach pad was constructed by compacting barren tailings in six inch layers and covering them with a thin PVC liner. The heaps were built by adjusting the radial-arm stacker to its lowest angle, sweeping across the width of the pad, raising the stacker discharge end one foot (30 cm), and sweeping the opposite direction across the width of the pad. This procedure continued until the heap was 16 ft (5 m) high. The stacker remained at 16 ft (5 m), and new agglomerates were added to the heap by sweeping the stacker across the width of the pad and allowing the agglomerates to cascade down the heap. Heaps built in this manner avoided compacting the agglomerates. The agglomerating equipment and the stacker were moved as a unit by a dozer before a new row of agglomerates was added to the leaching pad. A width of PVC liner was rolled out the width of the pad and welded as necessary, to continue heap building. The agglomerates cured for several days while the 6,400 ton heap was built. The heap was leached by spraying a cyanide solution containing 2.0 lbs NaCN per ton (1 kg/mt) of solution on it at a rate of 0.003 gpm/ft² (0.002
The pregnant solution that drained from the sloped leaching pad collected in lined ditches and flowed by gravity to a pregnant solution pond. Gold was recovered from the pregnant solution by carbon adsorption-desorption-electrowinning.

Gold recovery by agglomeration-heap leaching was 78 percent. Cyanide consumption was 0.7 lb NaCN per ton (0.35 kg/mt) of tailings. The leaching-washing cycle was about 24 days.

5.8.2 Silver Agglomeration-Heap Leaching in Southeastern California

A tailings pile from a former flotation operation in southeastern California was processed by agglomeration-heap leaching to recover the contained silver values (Milligan and Engelhardt, 1983). The tailings were 90 percent minus 200 mesh and contained an average of 1.4 ounces Ag per ton (48 g/mt) of tailings. The operators of the property conducted both bench- and pilot-scale experiments to evaluate agglomeration-heap leaching for recovering silver from the tailings. Bench-scale results showed that 63 percent of the silver was recovered by agitated cyanidation and 72 percent of the silver was recovered by agglomeration-heap leaching. The longer leaching cycle for heap leaching allowed the higher recovery.

The plant was designed to agglomerate and heap leach 1,000 tons per day of dry tailings. The tailings were mined and crushed to break up the large chunks of cemented material. The crusher discharge was conveyed to two mixers where 35 lbs of portland cement per ton (17.5 kg/mt) of dry feed were added as a binder. The binder and feed mixture were conveyed to a 10 ft (3 m) x 30 ft (9 m) drum agglomerator. A scraper, which rotated in the opposite direction to the drum, was situated along the length of the drum to prevent agglomerate buildup. Water was applied as a coarse spray through a spray bar situated lengthwise in the drum. The water was added at the bottom of the drum and mixed with the tailings to bring the final moisture content to 12 to 15 weight percent. The agglomerates discharged from the drum to a transfer point feeding a radial-arm stacker. The green agglomerates were placed on a stockpile by the stacker and cured four days before being transported to the leaching pad.

The leaching pad was constructed from moistened clayey silt material compacted in three layers. The middle layer was mixed with bentonite to ensure impermeability of the leaching pad (van Zyl, 1984). The heaps were built to a height of 13 ft (4 m) by a front-end loader to avoid driving on the agglomerates.

The heaps were sprayed with a solution containing 2.0 lbs NaCN per ton (1 kg/mt) of solution and at a rate of 0.01 gpm/ft² (0.007 l/s/m²) (Milligan, 1983). The pregnant solution collected in lined ditches and drained by gravity to a pregnant solution pond. The pregnant solution contained an average of 1.0 ounce Ag per ton (34.2 g/mt) of solution and was pumped to the precipitation circuit at a rate of 150 gpm (9.5 l/s). The solution was clarified, deaerated, and contacted with zinc dust to recover the silver. Silver recovery was 72 percent after a 25 day leaching and 40 day washing cycle.

5.8.3 Gold Agglomeration-Heap Leaching in East Central California

A small tailings pile is being processed by agglomeration-heap leaching methods for recovery of gold and silver values. The operation is located in
east central California near the historic Mother Lode District. Approximately 130,000 tons of old milled tailings containing 0.070 ounces of gold (2.4 g/mt) and 0.75 ounces of silver (25.7 g/mt) per ton was available for processing. The tailings are 90 percent minus 200 mesh and contain excessive quantities of clayey minerals. The tailings are mined by front-end loaders and are transported by the loader a very short distance to a stockpile. Tailings from the stockpile are pushed by a tracked dozer into a hopper. The feed is conveyed from the hopper to a single one inch screen deck. The plus one inch (25 mm) clumps of clay are pushed to the side and are allowed to air dry for several days. The air dried clumps are broken up by driving over them with the tracked dozer, and are then placed back into the hopper.

Minus one inch material is conveyed to a 6 ft x 22 ft (1.8 m x 6.7 m) rubber lined drum agglomeration. Portland cement (20 lb/ton, 10 kg/mt, of feed) is added from a cement silo to the conveyor. The binder is mixed with the tailings in the first 1/3 of the drum. Water is added in the middle 1/3 of the drum to achieve a final moisture content for the agglomerates of 15 to 18 weight percent. Mechanical free tumbling in the last 1/3 of the drum produces strong and stable agglomerates.

A single heap of 75,000 tons of agglomerated tailings was built on a double lined clay pad using a series of conveyors and a radial arm stacker. The heap was built to a height of 24 ft (7.3 m). The agglomerated tailings were cured in the heap for about one week before applying leaching solution.

Leaching was conducted by applying cyanide solution containing 2.0 lbs NaCN per ton (1 kg/mt) of solution at a rate of 0.003 gpm per sq ft (0.002 l/s/m²) of heap surface area. A leach cycle of about three months was required to obtain targeted precious metal recovery. Pregnant solutions drained by gravity from the heap to a pregnant solution pond. Pregnant solution was pumped from the pond to a surge tank outside the zinc precipitation circuit building.

Solutions were clarified and deaerated before adding zinc dust. The zinc circuit processed 160 gpm (10 l/s) of pregnant solution. Precipitates were recovered in filter presses and were processed onsite to produce dore bullion. The dore bullion produced constituted about 65 percent gold and 30 percent silver.

The operation is currently building another pad to process the remaining tailings. Future plans are to process waste material from the old mining operation by agglomeration heap leaching using the present facility.

5.9 CONCLUSION

Agglomeration pretreatment of crushed ores and wastes, and finely ground tailings has been applied by the industry for the successful heap leaching of feeds that display poor percolation characteristics. Many feed materials percolate well without agglomeration. The need for agglomeration for a particular feed should be determined before committing a commercial operation to this processing technology.
5.10 REFERENCES


