Pulp Agglomeration Process and Application for Gold and Silver Heap Leach Operations

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Abstract

Pulp agglomeration is a hybrid heap leach and milling process in which a milled, high-grade ore slurry is blended with crushed low-grade ore and agglomerated with cement to allow for further processing and metal recovery by heap leaching. The main advantage of pulp agglomeration compared to a conventional cyanidation mill is that the pulp agglomeration circuit does not require a dedicated tailings storage facility because mill tailings are stored in the heap. Pulp agglomeration is a viable and proven alternative to conventional cyanide milling that has recently been implemented by Pan American Silver at their Dolores Mine, and has also been successfully used in the past at the Castle Mountain and Ruby Hill mines.

In a typical pulp agglomeration circuit, low and high-grade ore is crushed in a two- or three-stage conventional crushing circuit, and stockpiled. High-grade ore is reclaimed and ground using conventional grinding technology. The resulting slurry may be pumped to an agitated filter feed tank, which functions as a single-stage leach tank, followed by filtering, or the slurry may be sent directly to a thickener. Pregnant filtrate or thickener overflow solution is processed in a Merrill-Crowe or ADR plant that is shared with the heap leach circuit. The resulting filter cake or thickener underflow is mixed with crushed low-grade ore from the low-grade stockpile, agglomerated with cement, and stacked onto a leach pad for cyanide leaching. Pulp agglomeration provides several operating advantages, including faster and increased recovery of gold and silver values from the high-grade ore compared to heap leaching only, reduced capital and land requirements compared to a conventional mill with agitated leach and tailings impoundment, and operational flexibility for processing low- and high-grade ore.

This paper provides a general overview of the pulp agglomeration process, important design parameters and considerations for pulp agglomeration, and an overview of projects where pulp agglomeration has been used.

Introduction

Pulp agglomeration is a hybrid heap leach and milling process that has only been sparsely utilized in the mining industry. The process as discussed in this paper was first known to be utilized in the early 1990s at Viceroy Gold's Castle Mountain mine (Zaebst, 1994). However, a similar process, which considered combining a milled product with crushed material in an agglomeration drum for heap leaching, was previously implemented successfully by Comco, with assistance from KCA, in the late 1980s at Cerro Rico de Potosi in Bolivia (Rose et al., 1990). The novel approach allowed Castle Mountain to achieve higher recoveries from high-grade ore by grinding without having to construct a tailings pond, which would have taken considerable time and effort in permitting. Since the implementation at Castle Mountain, pulp agglomeration has been applied successfully at the Ruby Hill mine and Dolores mine, and has potential to be applied elsewhere.

The pulp agglomeration process consists of blending a ground product slurry (coarse or fine grind) with a crushed product and binding them with cement to form stable agglomerates for heap leaching. This can be accomplished using many different processing methods depending on the specific ore and project requirements. A typical flowsheet considers two product streams for low and high-grade ore. The low-grade ore is crushed as required for regular heap leaching, which may be accomplished using a conventional jaw and cone crushing plant, mineral sizers, gyratory crushers, high pressure grinding rolls (HPGR), etc. depending on the ore type, final crushed product size required, and throughput.

High-grade ore is similarly crushed, which can be accomplished using a shared crushing circuit and campaigning low and high-grade ore onto separate product stockpiles, or by separate dedicated crushing circuits, followed by grinding in a mill. Milling equipment and stages are dependent on the target grind size of the product. The milled product is dewatered, typically by filtering or thickening, before being recombined with the low-grade ore product and agglomerated with cement. If cyanide is present in the milling circuit, it is common to leach a significant portion of the recoverable metal values from the ore before final processing by heap leaching. Pregnant leach solution from the mill is collected as filtrate from the filtration system or thickener overflow solution and sent to the recovery plant. Filtrate solution is typically dirty, and may require a clarification step prior to processing in the recovery plant.

Agglomeration is typically accomplished using an agglomeration drum. The blend of low and high-grade ore, as well as cement addition requirements, are determined through test work on the material with typical blend ratios ranging from 2.5:1 to 4:1 low-grade to high-grade, but may be even higher. Depending on the characteristics of the filtered material, additional equipment, such as a mixer to break up the filter cake and blend cement or a re-pulping system to control moisture, may also be required.

Capital and operating costs for pulp agglomeration is largely dependent on the processing requirements and throughput of the project. In general, capital costs are lower compared to conventional cyanidation mill because the agitated leaching circuit and tailings storage facility are not needed. Depending on the tailings disposal method and site topography, the overall capital savings can be significant. Cement is the most significant added operating cost. This cost is typically in the range of US$0.50 and US$1.00 per total tonne processed, but can exceed US$2.00/tonne. This is partially off-set by cyanide destruction savings, which is not required for pulp agglomeration and lime requirements as the cement acts as the pH buffer for the heap.

Pulp agglomeration design considerations and parameters

Important design considerations for pulp agglomeration include recovery improvements for gold and silver by grinding versus conventional heap leaching, ratio of low-grade to high-grade ore (both available, and required), dewatered high-grade ore moisture content, cement addition requirements and material properties. These design considerations must be supported by the mine plan (with respect to low-grade and high-grade material available for blending) and project economics. There will also be some logistical challenges, such as the availability and delivery of the large quantities of cement that may be required. In order to evaluate and develop a potential pulp agglomeration project, a detailed and thorough laboratory test program is necessary.

Column and bottle roll leach tests, including grind size versus recovery tests, are necessary to estimate final recoveries and select target crush and grind sizes. These tests will also enable designers to determine if there is an economic benefit for milling with cyanidation of the high-grade ore versus conventional heap leaching or other recovery method (such as gravity or flotation). Characterization work including abrasion and work indices, specific gravity, and multi-element analyses of the material can be performed as part of the initial leaching program. Once a target grind size is selected, rheology, filterability and thickening test work should be performed to determine the dewatering potential for the high-grade slurry.

Heap permeability is the most significant risk for pulp agglomeration due to the introduction of a large quantity of fines to the heap. In order to mitigate this risk, a detailed compacted permeability test program is critical. Compacted permeability testing simulates heap conditions under simulated loads and evaluates the performance of the heap based on permeability, material slump, and solution clarity. In a typical compacted permeability test program, material is tested under the simulated load of the maximum heap height at various cement addition rates; stage loading at different heap heights may also be considered. A failure in solution flow (permeability) or slump indicate that the heap will most likely not perform well under the expected conditions. A failure in solution clarity suggests a migration of fines, or degradation of agglomerates; however, if the sample passes based on solution flow and slump, a failure for solution clarity does not necessarily mean the heap will not perform well. A typical compacted permeability test apparatus is presented in Figure 1.

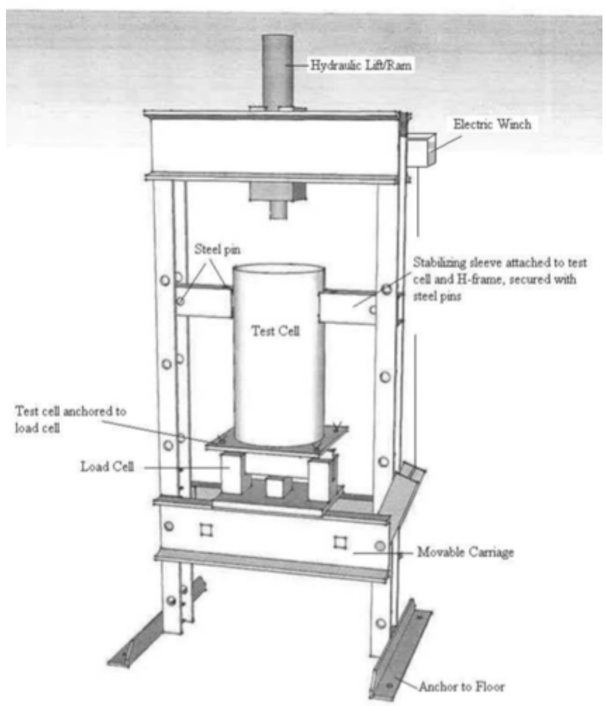

Figure 1: Compacted permeability test apparatus

Compacted permeability testing for pulp agglomeration should include multiple candidate blending ratios of high-grade ore at the target grind size and crushed low-grade ore at different cement addition rates. Depending on the results, adjustments to the ratio of low-grade to high-grade ore, cement addition rate or moisture could be considered to improve the simulated conditions. Once a target blend ratio and cement addition rate is selected, confirmatory tests should be performed to ensure the results are repeatable. It is important that all test work be performed on representative samples.

Pulp agglomeration projects

Castle Mountain

Operating parameters and process description for the historical Castle Mountain pulp agglomeration process are summarized directly from Zaebst (1994). A simplified flowsheet is presented in Figure 2.

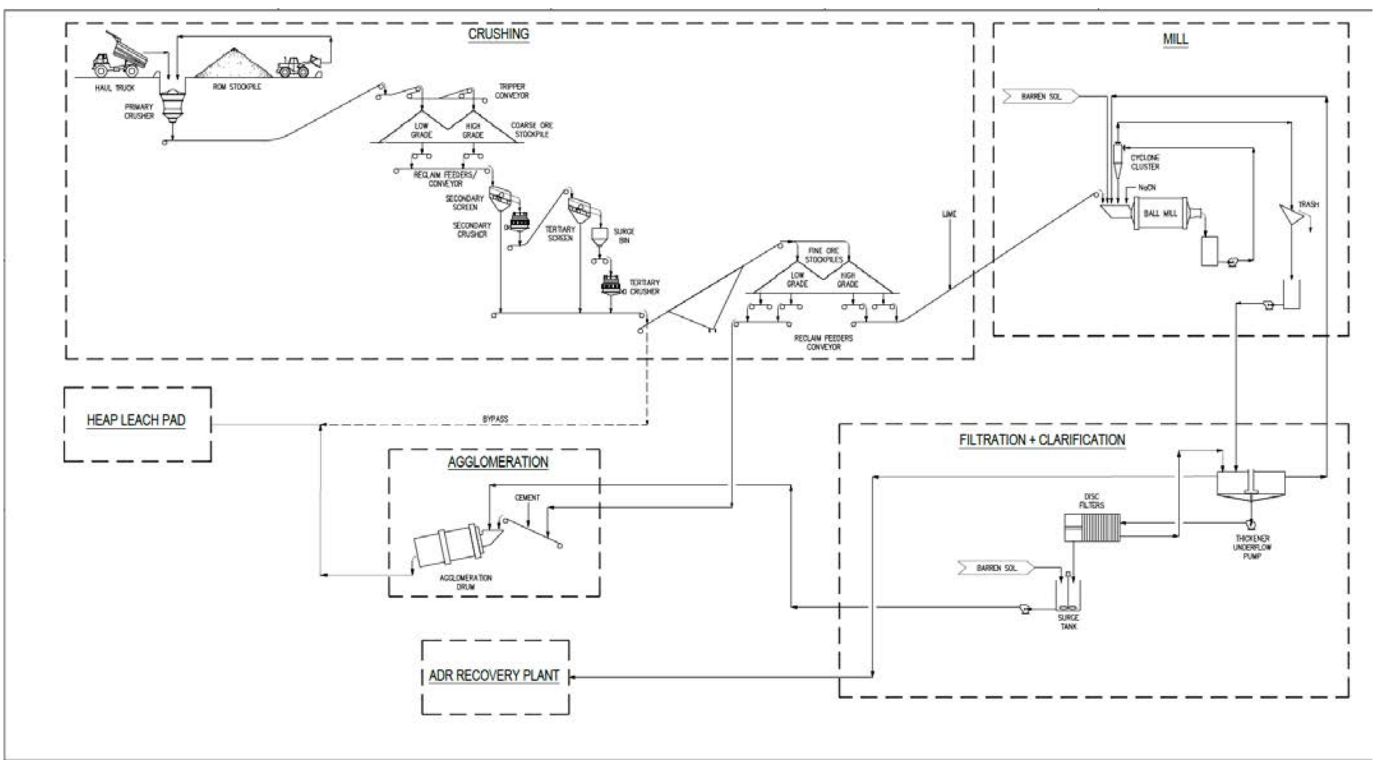

Figure 2: Castle Mountain pulp agglomeration simplified flowsheet

Key design parameters

Key design parameters for the historical Castle Mountain pulp agglomeration process are summarized in Table 1.

Table 1: Key design parameters for the historical Castle Mountain pulp agglomeration process

Item	Design parameter
Low-grade production rate	8,000 tons per day
Low-grade crushed product size	P80 3/8”
High-grade production rate	1,200 tons per day
High-grade crushed product size	P80 100 mesh
Low-grade : high-grade ratio at agglomeration drum	3.5:1
Overall low-grade : high-grade ratio	6.7:1
Cement addition	8 lb per ton of ore

Process description

Low- and high-grade ores at the Castle Mountain project were crushed to 80% passing 3/8" in a shared three-stage, open crushing circuit. Primary crushing was accomplished using a gyratory crusher with secondary and tertiary cone crushers. The final crushed product was conveyed directly to the leach pad by an overland conveyor, or was stockpiled onto an 8,500 ton fine ore stockpile. A radial stacker was used to direct ore to the high-grade stockpile for further processing by milling, or to the low-grade stockpile to feed the agglomeration drum.

Grinding for high-grade ore was accomplished in a single stage using a 1250 HP 12' × 16' ball mill. Ore was ground in a barren process solution with lime added for pH control. The ball mill product was pumped to a cyclone cluster for classification to produce a final product at P_{80} 100 mesh. The cyclone overflow discharged across a vibrating trash screen before being pumped to a thickener, and cyclone underflow was recycled back to the ball mill. The mill product was thickened to approximately 65% solids before being pumped to two disk filters. Filtrate from the disk filters reported back to the thickener and the resulting filter cake was then re-pulped to 69% solids using process solution for agglomerate moisture control, before being pumped to the agglomeration drum. Overflow from the thickener solution was directed to the carbon adsorption circuit for recovery of gold values from solution.

Agglomeration of crushed low-grade ore and high-grade slurry was accomplished in a 9' × 34' agglomeration drum, with cement added at 8 lb per ton to produce agglomerates with a moisture content of 9 to 10%. Discharge from the agglomeration drum was combined with other low-grade ore and conveyor stacked onto a heap leach pad in 30-ft lifts, before being leached with a low strength sodium cyanide solution. Gold and silver values from the pregnant heap leach solution were recovered in the carbon adsorption circuit. Loaded carbon was then acid washed, stripped using a high-pressure, high-temperature desorption circuit, and regenerated. Gold and silver from the pregnant strip solution were recovered by electrowinning and smelted to produce doré bars.

Ruby Hill

Operating parameters and process description for the historical Ruby Hill pulp agglomeration process are summarized directly from Jones (2000). A simplified flowsheet is presented in Figure 3.

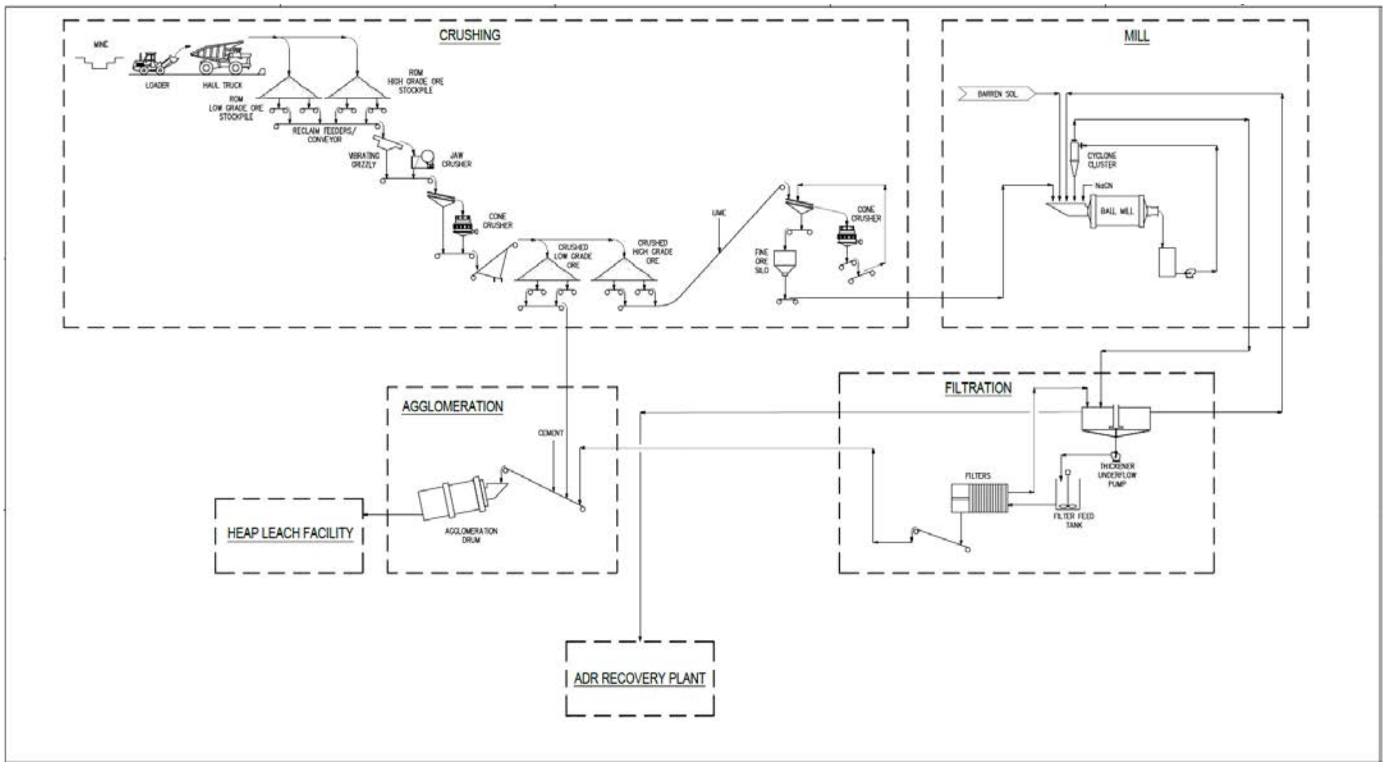

Figure 3: Ruby Hill pulp agglomeration simplified flowsheet (Jones, 2000)

Key design parameters

Key design parameters for the Ruby Hill pulp agglomeration process are summarized in Table 2.

Table 2: Key design parameters for the Ruby Hill pulp agglomeration process

Item	Design parameter
Low-grade production rate	1,600 to 3,150 tons per day
Low-grade crushed product size	P100 1.5 inch
High-grade production rate	900 tons per day
High-grade crushed product size	P85-90 65 mesh
Low-grade : high-grade ratio	1.8 to 3.5 : 1 (depending on low-grade availability)
Cement addition	8 lb per ton of ore

Process description

Low and high-grade ROM ores at Ruby Hill were crushed in a shared two-stage crushing circuit consisting of a primary jaw and a secondary cone crusher. Ore was crushed to minus 1.5" and then stockpiled by grade using a radial conveyor. High-grade ore was reclaimed and further crushed to minus 3/8" using a tertiary cone crusher before grinding with cyanide solution to 85 to 90% passing 65 mesh in a 10.5 × 16' ball mill. The ball mill product was pumped to a cyclone for size classification with the cyclone overflow being thickened to 50% solids. Overflow from the thickener was pumped to the carbon column (CIC) circuit for gold recovery, and thickener underflow was pumped to an agitated, air sparged leach tank before filtering in two vacuum-assisted belt filters. Approximate gold extraction averaged 90%, with 85% of high-grade ore extraction occurring in the mill and thickener.

Filtered cake from the belt filters (approximately 21% moisture) was combined with low-grade crushed ore at an average ratio of 1:2.5 and agglomerated with cement in an agglomeration drum. The pulp agglomerates were then conveyor stacked in 30 feet lifts and leached using barren cyanide solution. Moisture content of agglomerates averaged 12%.

Pregnant solution from the heap was pumped to the CIC circuit from a pregnant solution tank along with overflow from the thickener circuit. Loaded carbon was acid washed with nitric acid before being stripped in a high temperature high pressure desorption circuit. Gold from pregnant strip solution was recovered by electrowinning with the resulting gold sludge being processed in a retort for mercury recovery and smelting to produce doré.

Dolores

Operating parameters and process description for the Dolores pulp agglomeration project are shared with Pan American Silver's permission, based on work completed by Kappes, Cassiday & Associates (KCA) and the Pan American Silver team. KCA was responsible for the detailed Engineering, Procurement and Construction Management of the Dolores Pulp Agglomeration Mill, which was completed in 2016. A simplified flowsheet is presented in Figure 4.

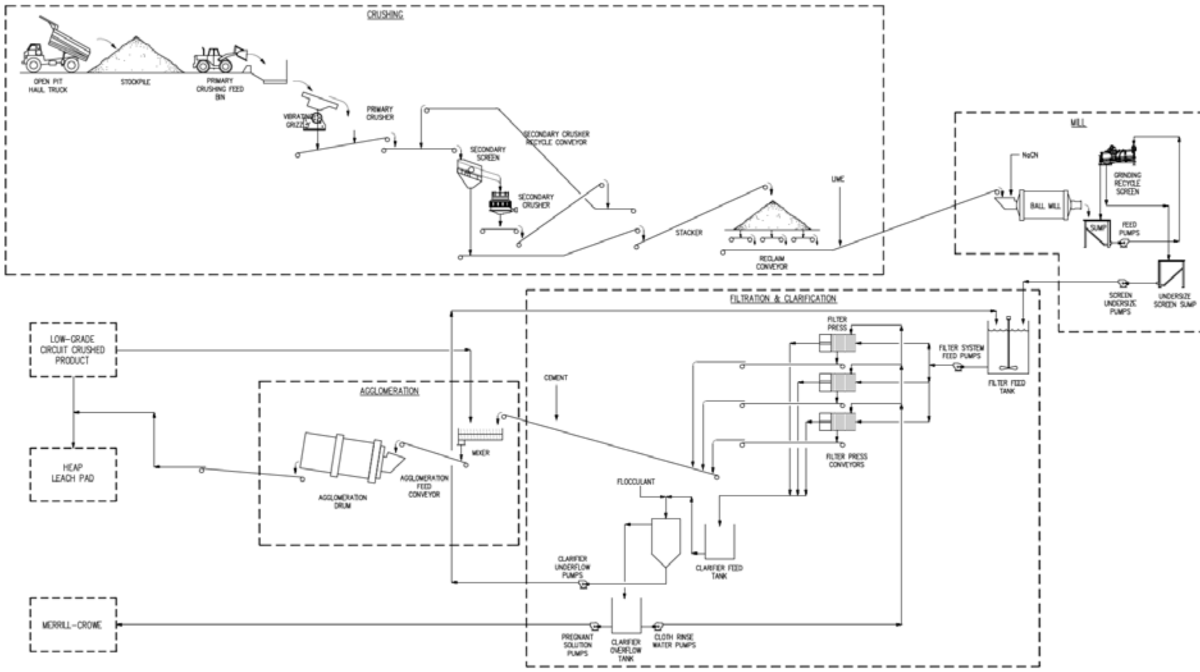

Figure 4: Dolores pulp agglomeration simplified flowsheet

Key design parameters

Table 3

Item	Design parameter
Low-grade production rate	15,860 tonnes per day
Low-grade crushed product size	P_{80} 8 mm
High-grade production rate	5,440 tonnes per day
High-grade crushed product size	P_{80} 425 micron
Low-grade : high-grade ratio at Drum	1:1
Overall low-grade : high-grade ratio	2.9:1
Cement addition	20 to 30 kg per ton of high-grade

Process description

Pulp agglomeration at the Dolores Mine was designed as an expansion of their existing heap leaching circuit to process high-grade underground and open pit ore. High-grade ore is crushed at an average rate of 5,440 tonnes per day to 100% passing 23 mm in a dedicated two-stage, closed crushing circuit consisting of a primary jaw crusher and secondary cone crusher. Crushed ore is stockpiled before being reclaimed and milled in two stages to a final product of 80% passing 425 microns. The grinding circuit includes an open circuit primary rod mill and closed circuit secondary Vertimill (tower mill) with a vibrating wet screen for material classification; cyanide is added to the rod mill to start the leaching process.

The final milled product is pumped to an agitated, aerated filter feed tank, which acts as a single-stage leach tank, and is then pumped to three vertical plate filter presses (2.5 m × 2.5 m) operated in parallel. The ground ore is filtered to 86% solids by weight before being conveyed to a mixer where cement is added at a rate of 20 to 30 kg per tonne of high-grade ore along with low-grade ore in a one-to-one ratio.

Initially, the process also included a "delumper" for breaking up the filter cake ahead of the mixer, but this equipment was later determined to not be necessary. The high-grade ore, low-grade ore and cement are mixed and large filter cake lumps are broken up in the mixer before being fed to a 3.6 m × 10 m agglomeration drum. The ore is agglomerated to 11% moisture by weight and combined with crushed low-grade material on an overland conveyor for an overall low-grade to high-grade ratio of 2.9:1, which feeds the existing conveyor stacking system.

Pregnant filtrate from the filter presses is transferred to a pin bed clarifier to remove suspended solids, which are pumped back to the filter feed tank. The clarified pregnant leach solution is pumped to an existing Merrill-Crowe recovery plant and refinery, where it is processed along with pregnant leach solution from the heap leach to produce the final doré product.

A picture of the Dolores pulp agglomeration mill is presented in Figure 5.

Figure 5: Pan American silver pulp agglomeration mill expansion (designed and built by KCA)

Conclusion

Pulp agglomeration, although not applicable to every milling and heap leach operation, is a proven and viable processing method, and should not be discounted when evaluating process options. Pulp agglomeration provides several capital and operational advantages compared to conventional heap leach and milling operations, including faster and improved recovery of gold and silver values from the high-grade ore by grinding compared to heap leaching, reduced capital and land requirements compared to a conventional mill with agitated leach and tailings impoundment, and operational flexibility for processing low- and high-grade ore. Despite the benefits, pulp agglomeration has several distinct risks, primarily the increased risk of permeability issues in the heap. Test work is critical for a successful operation and should include blending optimization for high- and low-grade ore and compacted permeability tests to ensure stability and permeability of the heap.

Overall, the pulp agglomeration process has been well demonstrated, and although the process is site/deposit specific, it is a valid application that may be underutilized in the industry.

Acknowledgements

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