Minerals Engineering 106 (2017) 2–6

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Commercial heap biooxidation of refractory gold ores – Revisiting Newmont's successful deployment at Carlin

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ARTICLE INFO

Article history:
Received 2 August 2016
Accepted 23 September 2016
Available online 6 October 2016

Keywords:
Biooxidation
Commercial heap leach
Refractory gold ore
Scale-up

ABSTRACT

Newmont Mining Corporation pioneered the investigation, development, and commercial-scale implementation of refractory gold whole-ore heap biooxidation, during a period spanning 1988–2009 at Carlin, Nevada. Basic and applied research and development from 1988 to 1999 included laboratory test work and increasingly larger pilot test heaps culminating in the full-scale implementation of a process that was estimated to contribute 120,000–180,000 oz/year to Carlin's production between 2000 and 2005. Key parameters that influenced performance of the on-off heap biooxidation process, and factors that led to the discontinuation of the operation are described.

1. Introduction

Newmont Mining Corporation pioneered the investigation, development, and commercial-scale implementation of refractory gold whole-ore heap biooxidation, during a period spanning 1988–2010 at Carlin, Nevada (Fig. 1 summarizes key developments and gold price during this period). Basic and applied research and development from 1988 to 1999 included laboratory test work and increasingly larger pilot test heaps leading to full-scale implementation of a process that was estimated to contribute 120,000–180,000 oz/year (12.2 t total by May 2005; Logan et al., 2007) to Carlin's gold production from 2000 to 2005. Even within Newmont, it is difficult to determine exactly when the closure of the commercial operation (internally referred to as the Refractory Leach Project) occurred, but by combining U.S. Securities and Exchange Commission annual 10-K reports and internal reports, it can be concluded that initial planning for project closure began in 2007, operating data exist for 2008 and 2009, and a 2011 final closure plan for the biosolution pond described cessation of operations in 2010. It is likely then that the commercial biooxidation plant contributed at least another 5 tonnes (ca. 160,000 oz) of gold to Carlin production before closure in 2010, after a decade of operation.

Brierley et al. (1995) summarized the pilot heap tests that predated the Gold Quarry biooxidation demonstration facility (Schutey-McCann et al., 1997), a $13.5 million project that constructed and operated an 800,000 t/year large-scale pilot that integrated lessons learned from the early, smaller heap tests. This facility was operated from 1994 to 1997, and the biooxidation and ammonium thiosulfate leach pads were ultimately enlisted to validate "bio-milling" at Carlin's Mill 5 carbon-in-leach (CIL) facility in conjunction with the commercial biooxidation process.

Initial bench-scale work to test the feasibility of biooxidizing Carlin low-grade refractory gold ores began in 1988 at Newmont's central metallurgical services laboratory, then located in Salt Lake City. Carlin-type ore is typified by microscopic or dissolved gold disseminated in pyrite, arsenopyrite, or arsenian pyrite hosted within carbonaceous sediments. Concerns regarding increasing sulfide content in Gold Quarry ore at that time justified an examination of biooxidation as an alternative processing strategy for low-grade refractory ore.

2. Small pilot heap test summary

A Refractory Leach Test Facility to construct the first small pilot heap (476 t) was authorized by Newmont management in 1990, and constructed adjacent to the Gold Quarry pit at Newmont's Carlin Mine. By 1994, a series of successively large heaps were operated in different areas of the Carlin mine (North and South Areas), ranging from 476 t to 25,900 t. Many concepts that have become accepted practice in commercial copper bioleaching and were used during operation of Newmont's commercial whole-ore biooxidation pads were tested during this period, including use of drip emitters, rather than wobbler, or impact head sprinklers, use of Wilfley diffusers in bacterial production bioreactors, the beneficial effect of rest periods on bacterial activity (as measured by accumulated ferric iron and increased E_h in leach solution),

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http://dx.doi.org/10.1016/j.mineng.2016.09.017
0892-6875/

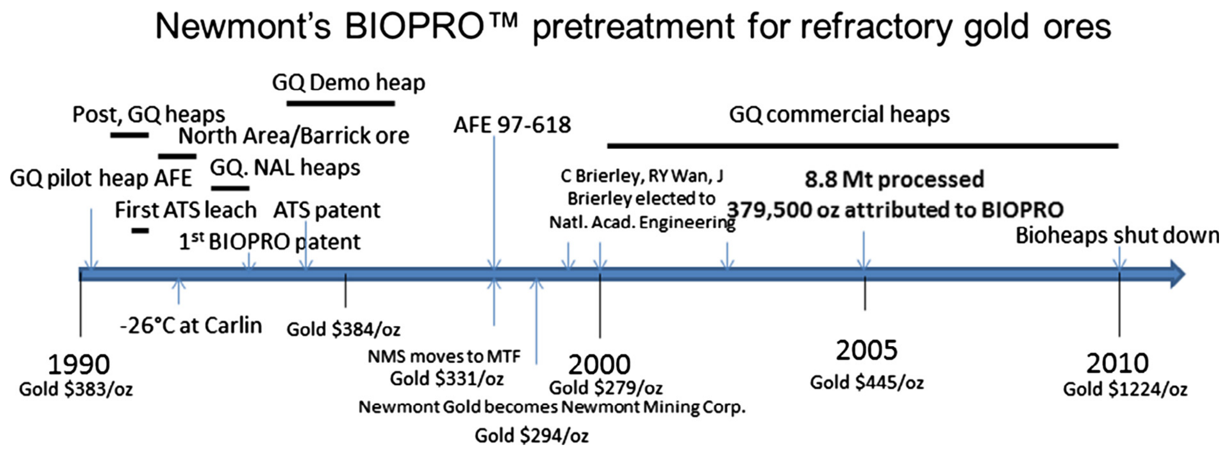

Fig. 1. Timeline of developments leading to Commercial Refractory Leach Facility.

and observation that mesophilic iron-oxidizing bacteria such as *Leptospirillum* and moderately-thermophilic bacteria such as *Sulfobacillus* emerge without inoculation and are presumably enriched from the environment as sulfide minerals are oxidized.

Newmont evaluated heaps that contained not only siliceous, sulfidic, refractory (SSR) ore, but also carbonaceous, sulfidic, refractory (CSR) ores that possess significant ability to remove cyanide-complexed gold (so-called "preg-robbing" ore), generally thought to be a function of non acid-soluble, organic carbon in the ore. The test heaps included variations in sulfide sulfur, clay, preg-robbing carbon, carbonate, biooxidation cycle, and particle size.

Belt agglomeration with a substantial (10^6–10^7 cells/mL) quantity of microbial inoculum (*Acidithiobacillus ferrooxidans*) reduced to practice what would become Newmont's patented BIOPRO® technology, with 4 related patents (Brierley and Hill, 1993, 1994, 1998, 2002, 2004). Heaps were stacked with either a front-end loader or radial stacker (larger heaps).

The acidic conditions of biooxidation created within the heaps precluded direct leaching with cyanide or other gold complexing agents. Ore was off-loaded from the heaps with a front-end loader and partially neutralized with cement, caustic, or lime addition to achieve alkaline pH. Gold extraction with cyanide, thiourea, or ammonium thiosulfate (ATS) was tested. It was concluded that thiourea was ineffective perhaps due to the large particle size of the ore, while ATS yielded results equivalent to, and in several cases better than cyanide. Newmont patented the ATS process for gold leaching from preg-robbing ores (Wan et al., 1994) and tested this approach at larger scale in the subsequent Gold Quarry demonstration. The coupling of this lixiviant to biooxidation of preg-robbing ores was initially planned to be a key feature of the commercial whole-ore biooxidation facility. Barrick Goldstrike recently achieved commercial production of gold using the Total Carbonaceous Material (TCM) leach process based on calcium thiosulfate in the 3rd quarter of 2015 (Barrick Gold Corporation, 2016).

Other significant parameters important to operation of biooxidation heaps for refractory gold ore that emerged from these tests included: (a) defining a lower limit for sulfide-S content of 0.2–0.4%, (b) crushing to a smaller particle size is not always better for biooxidation within the heap, particularly with the presence of clays, and (c) carbonate content up to 2.2% could be accommodated in spite of the requirement of low pH conditions to promote growth of the iron-oxidizing bacteria, although considerable sulfuric acid addition was necessary to achieve pH control. It is interesting that active aeration through the use of a blower and air distribution lines at the base of the heap was tested during this time as well, but the benefit was not clear, although it was noted that heap residues appeared to indicate uniform biooxidation had occurred throughout the heaps and might be attributed to aeration.

A record low temperature for the region (−26.1 °C) was experienced in December 1992 and caused concern, although the heap internal temperatures were observed to remain about 10 °C. A solution heater was introduced to prevent freezing of the recirculating solution but did not appear to have measurable benefit on the process within the heap.

Finally, the cost for biooxidation of refractory gold ores in heaps was estimated at that time to be within the range of $4–6/t. The commercial plant costs were later found to be at the low end of this range.

3. Gold Quarry demonstration

The scale-up of facilities to process up to 800,000 t/year of low-grade (1–3 g/t Au) siliceous sulfidic refractory (SSR) and carbonaceous sulfidic refractory (CSR) ores on five 136,000 t leach pads required a bacterial production capability that incorporated six 200 m^3 (1200 m^3 total) tanks started in batch mode, ultimately producing 800 m^3/day in continuous mode flowing into two solution storage ponds: a conditioning pond with a capacity of 800 m^3, and an operating pond of 2377 m^3 volume. An acid neutralization plant was part of the initial design for the facility, but no data could be located in internal documents or published reports that described details of operation or performance. Crushing utilized the existing Gold Quarry crushing circuit to generate nominal −19 mm material after passage through a gyratory crusher and cone crushers.

Target ore composition included 5–15% clay, 1.5–2.5% sulfide-S, and 0.07–0.5% acid-soluble carbon (the CSR material contained 1% organic carbon versus 0.07% in the SSR material).

Two methods of heap stacking were evaluated, comparing conveyor stacking with truck-dumped ore. Ore was stacked to a height of 10 m. Ore was inoculated at a rate of 24 L inoculum/t at the load-out conveyor for the haul trucks in the case of truck-stacked ore, while it was sprayed over the crushed ore at a portable feed hopper dropping ore onto the conveyor-stacker train at 18 L/t for conveyor-stacked heaps. Five different heaps were constructed to test liner designs including clay and HDPE, as well as combinations with clay base, and drain rock. No details were available regarding this evaluation, although it is presumed that the results were considered in the final commercial plant design.