

Keynote Address: Newmont's contribution to gold technology

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Newmont is one of the few remaining large mining companies that was established in the early nineteenth hundreds. The company has a long, colourful and enviable history. This paper provides highlights of Newmont's business and technical history since its inception in 1916, its transition to a 'gold only' company in the early 1990s and progress since that time up until the present day.

Details of Newmonts current gold operations and its gold production profile for 2008 are also provided in the paper

Over the last 50 years Newmont has developed a host of innovative gold technologies to meet the challenges of treating the complex refractory gold ores, found at the company owned mines in the Carlin region and around the world. Details of the technologies are provided and they include chlorination, roasting, bacterial and pressure leaching, leaching gold with thiosulphate and thiocyanate, N²Tech flotation, HPGR treatment of hard and abrasive ores and, finally, the use of Hydro-Jex technology for improving gold recovery from heaps.

Introduction

Newmont is one of the few remaining large mining companies that was established in the early nineteenth hundreds. The company has a long, colourful and enviable history. The longevity of the company is closely related to Newmont's ability to rapidly adapt to changes in business cycles and to develop innovative technologies to discover, mine and extract minerals around the world during the 93 years of its existence. Newmont has had a long association with gold, starting with its investment in Anglo American in 1917, surviving the Great Depression as a gold company, finding and developing one of the largest gold districts in the USA (Carlin) during the 1960s and becoming the world's largest gold producer in 2002. Over the last 50 years Newmont has developed a host of innovative gold technologies to meet the challenges of treating the complex refractory gold ores, found at the company owned mines in the Carlin region.

This paper provides a brief summary of Newmont's history since its inception, information on its current gold operations, plus details of Newmont's contribution to gold technologies during the last 50 years.

Brief company history

The Newmont Company was established in 1916¹ and headquartered in New York. The first major gold investment was made in 1917 with a 25% founding interest in Anglo American Corporation of South Africa. Newmont re-incorporated as Newmont Corporation in 1921 and went public in 1925, operating like a mutual fund, buying and selling stock in mining and oil companies. By the end of the 1920s Newmont owned large positions in Kennecott Copper, Hudson Bay Mining and Smelting, Texas Gulf Sulfur, Continental Oil, Standard Oil and purchased a share of Magna Copper, Arizona. The share price reached an all time high of \$236 in 1929.

With the start of the Great Depression in the early 1930s demand for metals and oils fell and Newmont's share price crashed to \$3.88 in 1932. The fixing of the gold price at US\$35/oz in 1932 made gold mining profitable. For this reason Newmont focused on gold mining until 1935¹. This strategy sustained the company during this period.

In 1940 Newmont traded for the first time on the New York Stock Exchange and the closing price on the opening day was \$73/share. During the 1940s Newmont acquired the Tsumeb Mine in South Africa and was also asked to help the cash strapped Mobil to finance offshore drilling in the Gulf of Mexico. This resulted in a joint venture that lasted for 40 years. In the 1950s Newmont invested large sums of money to support Sherritt-Gordon's development of its high temperature hydrometallurgical technology for base metal extraction. In addition to this, Newmont participated in investments in copper (e.g. Southern Peru Copper) lead, zinc, lithium, uranium and cement¹.

In 1957 the Newmont Danbury Research facility was opened and included a geophysical laboratory, a result of Newmont's successful funding and development of induced polarization¹ (IP) at other US laboratories in the late 1940s. This technology aided Newmont in discovering new ore deposits around the world. All the assets of the Magna Copper Mine were acquired in the late 1960s and Newmont's geologists discovered gold at Carlin, Nevada, in 1961 and the first gold was poured in 1965.

During the 1970s gold was found at the Telfer gold deposit in Western Australia and the first gold was produced in 1977. By the mid 1980s it was the largest gold producer in Australia. A consortium lead by Newmont acquired the Peabody Coal Company in 1977 and at the time this was the largest corporate buyout in American history¹.

The Gold Quarry mine in Nevada was discovered by Newmont in the early 1980s and produced more than 25 million ounces of gold over the next 25 years. By the end of the 1980s gold production at Newmont's operations in

Nevada reached almost 1.5 million ounces. This was the first time a US gold producer exceeded 1 million ounces of gold production in a year. The 1980s was a turbulent time for Newmont with a number of takeover attempts. The first was by Consolidated Gold Fields (ConsGold) and was offset by a standstill agreement resulting in ConsGold becoming the largest shareholder in Newmont. During the latter part of the 1980s, due to six years of consecutive losses, Newmont decided to divest its holding in Magna Copper, while minority interests in the Carlin and Australian gold operations were sold to the public. This provided the impetus for a takeover bid by T. Boone Pickens as Newmont was 'flush' with cash and its share price was at a discount to the net worth. The bid was thwarted by paying a \$2.2 billion dollar dividend (\$33/share) via 'debt raising,' and Newmont spent the next two years selling non gold assets to cover the debt. The last takeover attempt was made by Minorco, but legal manoeuvring by Newmont and ConsGold preserved Newmont's independence. In 1988, Newmont moved its headquarters from New York to Denver.

In the early 1990s Newmont sold its interest in Peabody Coal and for the first time became a pure gold company. Gold production started at Newmont's managed and owned gold mines at Yanacocha, (heap leaching) in Peru, that was discovered in 1988, the Zarafshan Gold Mine (heap leaching) in Uzbekistan, and the Minahasa Gold Mine (roasting a refractory gold ore) in Indonesia. Construction of the large Batu Hijau copper-gold mine in Indonesia commenced in 1996 and production started in 1999. Also, a hostile takeover by Newmont of the Santa Fe Pacific Gold increased Newmont's gold production. The additional production coming from the newly acquired Lone Tree and Twin Creeks gold mines. The Newmont Malozemoff Technical Facility (metallurgical, analytical and geophysical laboratories) opened in Denver in 1996. The gold price reached a 20-year low in 1999. This provided the impetus to increase gold production at the Yanacocha gold mine where operating costs per ounce were some of the lowest in the world.

In 2002 Newmont became the largest gold producer when it acquired Normandy Mining of Australia and Franco-Nevada of Canada, and retained this position until 2006 when Barrick acquired Placer Dome. Construction of the Ahafo Gold Mine in Ghana commenced in 2006, and the first gold was produced in 2007, while construction of the Boddington Gold Mine, in Western Australia, started in 2007. The Boddington treatment plant is currently being commissioned. The Miramar Mining Corporation was acquired in 2008 and with this came the Hope Bay project in the Canadian Arctic.

Newmonts gold operations and gold production (2008)

Newmont has operating gold mines on five continents: North America (Nevada), South America (Peru), Africa (Ghana), Australia and Indonesia. Details of the operating mines are as follows:

North America, Nevada

Newmont has been mining gold in Nevada since 1965. Nevada operations include Carlin (Mill 5 and Mill 6) located west of the city of Elko, the Twin Creeks mine, located approximately 15 miles north of Golconda, and the Midas mine near the town of the same name. The Phoenix mine, located 10 miles south of Battle Mountain, commenced commercial production in the fourth quarter of 2006.

Seventy-two per cent of Nevada's gold production in 2008 was generated from treating refractory gold ores. Higher-grade oxide ores are processed by conventional milling and cyanide leaching at Carlin (Mill 5) and Twin Creeks (Juniper). Lower-grade ores with suitable cyanide solubility are treated on heap leach pads at Carlin and Twin Creeks. Higher-grade refractory ores are processed through either a roaster at Carlin (Mill 6) or autoclaves at Twin Creeks (Sage mill). Lower-grade refractory ores are processed at Carlin by either bio-oxidation/flotation or direct flotation at Mill 5. Ores from the Midas mine are processed by conventional milling and Merrill-Crowe zinc precipitation.

At the Phoenix mill a copper-gold flotation concentrate is produced and sold to a smelter. The flotation tailings are treated in a carbon-in-leach cyanide circuit to recover the remaining gold.

South America, Peru

The properties of Minera Yanacocha S.R.L. ('Yanacocha') are located 48 kilometres north of the city of Cajamarca, in Peru. Yanacocha began production in 1993 and Newmont holds a 51.35% interest in Yanacocha.

Yanacocha has four leach pads, three gold recovery circuits and a new milling circuit (single stage SAG mill, CIL and SART cyanide recovery circuit for high copper-silver ores) which was commissioned in the second quarter of 2008.

Indonesia, Sumbawa

The Batu Hijau mine is located on the island of Sumbawa. Batu Hijau is a large porphyry copper/gold deposit, which Newmont discovered in 1990 and start up occurred in late 1999. The treatment plant consists of a standard SABC grinding circuit, followed by conventional flotation to produce a copper-gold concentrate for sale to smelters.

Africa, Ghana

The Ahafo operation Gold Mine is located in the Brong-Ahafo Region of Ghana. Ahafo commenced commercial production in August 2006. The treatment plant consists of a standard SABC communication circuit followed by a CIL for gold recovery and a two-stage CCD circuit for cyanide solution recovery.

Australia and New Zealand

The Tanami operations, that include the Granites gold treatment plant and associated mining operations, are located in the Northern Territory approximately 550 kilometres northwest of Alice Springs. Ore from the Tanami operations is processed through the Granites treatment plant. The plant comprises a three-stage crushing plant, ball milling and a conventional CIL circuit for gold recovery.

The Jundee Gold Mine is situated approximately 700 kilometres northeast of Perth in Western Australia. Ore at Jundee is sourced from underground mining and supplemented with oxide ore from stockpiles for blending purposes. The treatment plant comprises a conventional SABC and CIL circuit for gold recovery.

The Waihi Gold Mine is located within the town of Waihi, located approximately 110 kilometers southeast of Auckland, New Zealand. Ore is obtained from the Favona underground deposit and the Martha open pit, this is treated in a conventional SABC and CIP circuit for gold recovery.

The Kalgoorlie operations consist of the Fimiston open pit (the Super Pit) and the Mt. Charlotte underground mine, which are located on the outskirts of the city of Kalgoorlie-Boulder, Western Australia. The mines are managed by Kalgoorlie Consolidated Gold Mines Pty Ltd for the joint venture owners, Newmont and Barrick, each of which holds a 50% interest. The telluride gold ores at KCGM are refractory and require roasting prior to cyanide leaching. The treatment plant comprises a conventional SABC grinding circuit, followed by flotation and a CIL circuit to treat the flotation tailings. The flotation concentrate is roasted and then cyanide leached.

Gold production for 2008

Newmont's gold production² by region is shown in Table I.

Impetus for developing new gold technologies

The saying 'necessity is the mother of invention', truly reflects the impetus that led Newmont to focus and develop a spectrum of gold technologies that have been used at its Carlin operations, and other mines around the world. Each technology had/has a specific application and was implemented at the appropriate time in the life of the mines at Carlin.

As with all metallurgical processes the ore mineralogy ultimately dictates the selection of the treatment route. The mineralogy of the Carlin ores is extremely complex. Unraveling all the nuances of the gold and sulphide associations has been a challenge for Newmont's process mineralogists, as most of the gold is not visible under the strongest optical microscope.

A brief overview of the gold mineralogy in the Carlin region and how it affects gold extraction is given in the following two sections.

Mineralogy of gold ores in the Carlin region

Gold mineralization in the Carlin district occurs in marine-type sediments, chiefly siltstones and limey shales. Gold content varies considerably both vertically and horizontally and within a distance of a metre. Gold is in an extremely finely divided form in all the ore types found in the region.

Ores containing 0.06 to 0.25% organic carbon are designated as non carbonaceous ore (essentially non preg-robbing) and those with 0.25–0.8% organic carbon are designated as carbonaceous (mostly preg-robbing). In addition to carbonaceous material, the Carlin ores types contain up to 3% pyrite. Four distinct types of auriferous pyrite have been identified: coarse, fine grained microcrystalline and disseminated. The gold content of the pyrite is strongly related to the arsenic content (arsenian

pyrite and arsenopyrite) and the gold occurs as colloid particles and in solid solution in the sulphide matrix. Coarse, euhedral pyrite, 10 to 50 µm in size, is cubic with no internal porosity. The fine grained spheroidal pyrite occurs as isolated spherules or as clusters, ranging from about 0.5 to nearly 2 µm in size.

Overview of the treatment options for the Carlin gold ores

The oxide ores in the region are readily amenable to cyanidation either on heaps or in CIP or CIL circuits. The refractory characteristics of the ores that occur at depth can be traced to the organic carbon content (preg-robbing), sulphide content, sulphide encapsulation or silica encapsulation. These refractory ores require pretreatment that include chlorination, roasting, pressure and bacterial oxidation prior to treatment by cyanide to recover the gold.

Cyanide has problems leaching gold occurring in preg-robbing carbonaceous oxide ores or preg-robbing carbonaceous ores that have a low sulphide content. For these ores the chlorination process, used at the Newmont operations during the 1970s and 1980s, followed by cyanide leaching, was an effective and economic process to recover gold.

Roasting is the only process that can simultaneously oxidize the sulphides and the organic carbon in the Carlin ores, and achieve acceptable gold recoveries. High-grade refractory ores (>3 g/t gold), in which sulphide locking of gold occurs with preg-robbing carbonaceous matter, is treated by roasting followed by cyanidation in a carbon-in-leach (CIL) circuit. Sulphidic ores with low carbonaceous content are pressure leached prior to cyanide leaching.

Low-grade refractory ores (<3 g/t gold) do not contain enough value to justify milling prior to pre-treatment. For the low-grade sulphidic and carbonaceous refractory gold ores, Newmont has made use of sulphide oxidizing bacteria as a pretreatment process prior to gold recovery, and so provide an economical method to treat these ores.

The bio-oxidized carbonaceous sulphidic ores cannot be treated with cyanide solution because of the preg-robbing characteristics of the ore. A combined bio-oxidation-thiosulfate heap process was developed for high sulphide carbonaceous ores, and a direct thiosulfate leach process for low sulphide carbonaceous ores.

Details of gold technologies developed by Newmont

Chlorination of gold ores in Nevada

In the late 1960s a large tonnage of oxide ore in the Carlin

Table I
Newmont gold statistics for 2008

District/deposit	Gold sales (000 ozs)	Costs		Reserves			Metallurgical recovery (%)
		Operating (US\$/oz)	Total (US\$/oz)	Proven (000 ozs)	Probable (000 ozs)	Total (000 ozs)	
Nevada	2225	464	574	6,780	21,310	28,090	78%
Yanacocha	1843	354	443	960	11,800	12,760	74%
Australasia	1187	526	660	6,250	14,650	20,900	83%
Batu Hijau	299	406	505	2,110	1,980	4,090	76%
Ghana	521	380	537	230	16,810	17,040	88%
Other	180	451	675	1,070	1,010	2,080	65%
Total Average	6255	433	548	17,400	67,560	84,960	80%

Source: Newmont 2008 annual report

region was found not to be amenable to standard cyanidation technique because, of the presence, of activated carbon and long chained organic hydrocarbon-type compounds^{3,4}. The primary purpose for using chlorine at Carlin was to pretreat the carbonaceous and low pyritic ores. In the chlorination process, the ore is subjected to pre-oxidation treatment using chlorine gas to oxidize the carbonaceous and sulphidic components. This liberates gold from the sulphide and destroys the preg-robbing properties of the carbonaceous material.^{4,5,6}

In 1967 a research programme began at the U.S. Bureau of Mines Reno Nevada station, which showed that the deleterious effects of the carbonaceous materials in the Carlin-type carbonaceous ores could be overcome by oxidizing agents in aqueous pulps. After extensive bench scale work by the U.S. Bureau of Mines, Newmont Exploration Limited, and Carlin Gold Mining Company, the choice of oxidation agents for the Carlin ores was narrowed to either chlorine or sodium hypochlorite. The limited tonnage of ore available at the time dictated the use of chlorine.

The chlorination treatment plant was commissioned in 1971. The flowsheet included grinding, thickening, heating the pulp to 27° to 38°C before transferring the pulp to four agitated tanks sparged with chlorine. The total retention time for chlorination was 20 hours. The tanks were rubber lined and coated externally with urethane foam for insulation. Off-gases from the covered tanks were ducted to a scrubber where a soda ash solution was circulated. The reaction between chlorine and the soda ash forms sodium hypochlorite which was returned to the circuit to react with the ore pulp.

The chlorination plant consistently outperformed its original expectations, giving gold extractions in the 83 to 90% range. On going research during the operation of the plant indicated that the preferred chlorination pH conditions are in the range of 2.5–5. At very low pH (<2) chlorine utilization is low due to the high chlorine vapor pressure. As a result the concentration of the reacting chlorine species (HClO) in solution is low.

Newmont was granted a patent for the chlorination process.⁹

Double chlorination technology

In 1977, the Carlin mine installed a new oxidation process called 'double oxidation' that included high temperature (80° to 86°C) aeration followed by chlorination.^{6,7} The high temperature aeration step oxidized the amenable pyrite as well as some of the carbonaceous material. The chlorination step completed the oxidation of the two refractory components, however, at a much reduced consumption of chlorine.

The 'double oxidation' process significantly reduced chlorine consumption, however, with time the consumption steadily increased as the ore changed at depth (more sulphides) and by 1981 the consumption was around 23–36 kg/t of carbonaceous ore.

A number of patents were granted for the process.^{10,11}

The Flash chlorination process

Ongoing research during the 1980s at the Danbury laboratory to reduce chlorine consumption resulted in the development of the 'Flash Chlorination' process.^{7,8} Lower consumption was achieved by improving agitation efficiency via a new impeller design to provide high speed agitation and improve gas-liquid-solid interaction at the

pulp-gas interface. Laboratory bench-scale testing also indicated significant improvements to gold extraction compared to the standard Carlin chlorination process. During the study it was noticed that ores containing low amounts of carbonate minerals had low gold extraction. This was attributed to low neutralization potentials (Eh) for these ores during standard chlorination. By controlling the chlorination pH with caustic or lime, or by ore blending with high calcite/dolomite ores, the problematic ores could be treated successfully. Chlorination treatment usually took 2–4 hours and the new 'Flash Chlorination' reduced the time to 5–15 minutes.

A full-scale Flash chlorination plant engineered jointly by Outokumpu Engineering (Denver) and Newmont Gold was installed and tested during 1987 and 1988. Gold extraction increased by 4.5% over the standard Carlin chlorination process.

Newmont was granted a patent for the process.¹²

Roasting technologies for refractory gold ores

Roasting at Carlin, Nevada

By the late 1980s Newmont had around 20 million ounces of gold associated with carbonaceous sulphidic ores that were uneconomical to treat by the chlorination process. The oxide and low sulphidic ores were rapidly being depleted and there was a need to find a process route for the economic recovery of gold from the carbonaceous-high sulphidic ores.

In 1988 Newmont initiated a research and development program for treating refractory gold ores that would oxidize both sulphide and carbonaceous (preg-robbing) materials in a single step. Direct chemical processing, pressure oxidation, flotation, and whole-ore roasting were evaluated. Hundreds of tests were conducted and literally hundreds of chemicals were screened for potential use. The low temperature, oxygen enriched whole-ore roasting process was developed as part of the programme. The Newmont research team found that enriching the air with oxygen allowed the optimum roasting temperature to take place at lower than usual temperatures. Both refractory components in the ore were 'eliminated' at the lower temperature, allowing for a viable process to recover gold from the carbonaceous-high sulphidic ores.

Following successful laboratory test work and pilot-plant roasting campaigns in Germany a detailed engineering study began in early 1991 for the Mill 6 whole ore roasting plant at Carlin. Plant construction commenced in mid 1993 and the plant was commissioned at the end of 1994. The flowsheet included, crushing, dry grinding, ore preheating, roasting, waste heat recovery, gas cleaning, sulphuric acid production and gold recovery by conventional CIL technology.^{13,14}

The roasting flowsheet at Mill 6 incorporated many new technologies including the Krupp-Polysius air swept two compartment ball mill with an attached drying chamber, commonly referred to as a double-rotator. The double-rotator performs the drying, primary grinding, and secondary grinding in a single piece of equipment. The double-rotator that was installed at Carlin was the largest of its kind in the world at the time. Another innovation was the inclusion of the continuous fluid bed (CFB) Lurgi roaster, a novelty in the gold industry at the time.

Operating parameters for the roaster require temperatures around 550°C with oxygen enrichment and a maximum retention time of 10 minutes. Nearly all of the sulphide mineralization and approximately 30 per cent of the organic

carbon are oxidized in the roaster under these conditions. An additional retention time of 20 to 24 minutes is required, at temperature provided in the calcine coolers, to oxidize the balance of the organic carbon. Ongoing research over the years has led to further improvements to the roasting process.¹⁵⁻¹⁷

A number of patents have been granted to Newmont in the area of roasting.^{18,19}

Roasting at the Minahasa gold operation— Indonesia

Development of the whole-ore roasting process for Newmont's Minahasa gold operation, located on the North Sulawesi Island, is another example of the importance of metallurgical research at Newmont to develop an economic process for the treatment of refractory ores.

The sulphide content of ores in the Minahasa deposit were low (1% to 1.5% S) and most of the gold (essentially less than 0.1 μm in size) in the ore was found to be associated with fine-grained pyrite enriched in arsenic. Two different refractory ores in the deposit were identified, a siliceous pyritic ore and carbonate pyritic ore. The siliceous pyritic ore was defined as ore containing greater than 80% quartz while carbonate pyritic ore was defined as ore containing greater than 20% carbonate. The carbonate minerals in the ore were dolomite and calcite.

Laboratory pretreatment processes that were evaluated included acidic and alkaline pressure oxidation, chlorination, nitric acid oxidation and ultrafine grinding combined with pre-and post-oxidation and whole-ore roasting. The acidic pressure oxidation process yielded good gold recovery, however, it required a large amount of acid due to the high carbonate content. The other processes (except whole-ore roasting) were not acceptable due to either high reagent consumptions or the fact that the process was too complicated to operate in a remote region. Whole-ore roasting tests gave promising results with recoveries in excess of 90%. The challenge was how to apply the roasting process in the remote mine site and build a plant with a low capital cost. Simplicity of the operation was important.

Blending of siliceous and carbonate ores as roaster feed gave two advantages as the sulphur dioxide, generated from roasting of the sulphides, was captured by the decomposition products of carbonate minerals, especially dolomite. The need for an acid plant to remove the sulphur dioxide from the off-gas stream was thus eliminated.

The Minahasa treatment plant that included whole ore roasting was commissioned in 1997 and operated continuously until its closure in 2005.

Pressure oxidation technology for refractory gold treatment in Nevada

During the early 1990s, Newmont (Santa Fe Pacific Gold Corp.) conducted an extensive test programme on the use of pressure oxidation to treat sulphidic carbonaceous refractory gold ores from Twin Creeks mine in Nevada. The results indicated that pressure oxidation followed by carbon-in-leach (CIL) was the process of choice even though preg-robbing organic carbon was present in the ore.

Laboratory batch tests on the sulphidic ores showed that the optimum operating conditions included grinding to 80% passing 20 to 22 μm , temperature of 225°C, operating pressure of 690 kPa, oxygen overpressure and 120 minutes of retention time.

An extensive pilot plant study was initiated to confirm the laboratory batch pressure oxidation test results. The first indication of trouble was when the gold extraction from the pilot plant was found to be only 49% compared to 92% from the batch autoclave. Reducing the autoclave temperature from 225°C to 200°C increased the gold extraction significantly. However, for some ore types, gold extraction was still low, as much as 12% lower than the batch autoclave.^{22,23}

It was speculated that one possible cause of the low gold extractions was the low acid concentrations in the autoclave. Limestone was added to the problematic ores and gold extraction increased from 68% to 95%. Ore blending was also found to improve extraction. However, ore blending required special attention. For example, 95% gold extractions were achieved using ore blends consisting of 56% and 66% of the problematic ore. When the amount increased to 75% to 85% the gold extraction decreased to 70% to 77%, respectively.²⁴

Extensive electron microprobe studies indicated that there was an intimate association of gold with organic carbon in the autoclave product. However, no association was observed for the untreated ore samples. At this stage it was theorized that the gold was solubilized by chlorides and subsequently reduced by the organic carbon in the ore. Assays of the problematic ores confirmed the presence of chlorides, i.e., contamination from a combination of potassium chloride (used as an additive in the drill mud) and hydrochloric acid used in the field to determine the presence of carbonates. The results of a new set of tests conducted on core drilled without chloride contamination showed dramatic increases in gold extractions to 92%.

Both laboratory and pilot-plant data confirmed that the pressure oxidation was a suitable process for the treatment of Twin Creeks ores. Difficulties were encountered with ores containing low levels of carbonates. This resulted in conditions that allowed gold to be solubilized by chlorides. Reduction of this gold on the organic carbon resulted in low gold extractions by cyanidation. Controlling the acid level either by adding limestone and/or dolomite or proper blending of ores to the autoclave was an effective means of overcoming these problems. Lowering the temperature was also effective.

A number of pressure oxidation patents have been granted to Newmont.²⁵⁻³⁰

Flotation technology—N₂TEC flotation for refractory gold ores

During the early 1990s Newmont (previously Santa Fe Pacific Gold Corporation) initiated a research programme to develop an economic process to treat low-grade (0.93–3.10 g/t of gold) refractory ores. Typically these ores require a pre treatment process (such as pressure oxidation or roasting) to make them amenable to cyanidation. The low grade ores require a concentration step prior to pre-treatment in order for the combined processes to be economically feasible. Flotation is used to produce a high grade concentrate for further treatment. Conventional flotation using air was found to give poor results due to the oxidation of the reactive and disseminated gold bearing arsenian pyrite in the ore. The N₂TEC flotation technology using nitrogen to create an inert atmosphere during grinding and flotation was found to significantly improve gold recovery and selectivity for the reactive gold containing sulphides.

During the initial development phase of the technology, many pilot-plant flotation runs were completed to prove the technical viability of the process on a variety of ores types. A feasibility study was completed in 1995 and a recommendation was made to construct a N₂TEC flotation facility at the Lone Tree gold mine in Nevada. Plant construction started in 1996, and plant commissioning commenced in 1997. The N₂TEC technology was implemented at the Lone Tree treatment plant by covering the original flotation cells and recycling the captured gases along with additional nitrogen obtained from the on-site oxygen plant. The N₂TEC process was successfully operated from 1997 to 2007 in this mode.^{32,33}

A number of patents were granted for the N₂TEC technology^{34,35} and a subsequent patent was issued for the treatment of platinum group mineral flotation.^{36,37}

Bacterial leaching technology for refractory gold ore treatment

Newmont has used the capabilities of the mineral oxidizing micro-organisms (bacteria) to develop a process for the pretreatment of lower grade (0.09–2.0 g/t of gold) sulphidic refractory gold ores at Carlin. The bio-oxidation process results in the oxidation of sulphidic minerals with increased exposure of gold for subsequent gold recovery.

Development of Newmont's patented bio-heap (BIOPRO™ technology) technology to treat low-grade refractory gold ores began in 1989 and involved many laboratory column tests, pilot plant tests and large-scale demonstration plant tests in the late 1990s. The bio-oxidation-heap pretreatment process involves crushing ore followed by applying a solution containing the micro-organisms to the ore as the ore is stacked on plastic lined pads.^{38,39}

Commercial operation at the Carlin mine in the early 2000s consisted of crushing the ore to minus 13 mm and then bio-heap leaching for about 150 days to as many as 270 days, depending on the sulphide content. The ore is then removed from the pretreatment pad and rinsed prior to being trucked to the Carlin gold treatment facility at Mill 5. The ore is milled, cyanide leached and the gold recovered by CIL. Several years after the initial construction of the bio-leach pads a flotation plant was added to Mill 5 to recover any unoxidized sulphide sulphur remaining after the bio-heap treatment. The sulphide flotation concentrate is additional feed stock for the Mill 6 roaster and Newmont's autoclave operations in Nevada.

A number of patents have been awarded for the gold bio-heap leaching process.⁴⁰⁻⁴⁵

Thiosulphate leaching of gold from refractory ores

Newmont developed this technology for the recovery of gold from 'low-grade' carbonaceous sulphidic refractory ores that contained preg-robbing material.

A combined bio-oxidation-thiosulphate heap process was developed for the high-sulphide ores and a direct thiosulfate leach process for the low-sulphide ores.

The copper-ammonium-thiosulphate leaching process is a complicated system. The successful development and utilization of the ammonium thiosulphate process depends on a detailed knowledge of the system and control of the solution chemistry. Maximum control of the process to ensure stability of the thiosulphate system is an important factor for success, especially if it is to be applied in a heap leach application. Unlike cyanide, thiosulphate ions are metastable and tend to undergo chemical decomposition,

particularly in the presence of sulphides and copper. The degradation of thiosulphate not only results in the loss of lixiviant, but also leads to the formation of sulphides, which, in turn, passivate gold and limit the leaching rate.^{47,48}

The ammonium thiosulphate leach process was successfully tested at laboratory and pilot-plant scale. A demonstration heap leach facility was operated from 1996 to 1999. Around 1.3 Mt of low-grade carbonaceous refractory ore containing 1.4 to 2.4 g/t of gold was heap leached at Carlin with ammonium thiosulphate and produced around 55,800 ounces of gold. Each treatment campaign processed about 320 kt of low-grade carbonaceous refractory ore. Gold recovery was achieved with copper powder cementation. After gold recovery, the barren solution was recycled back to the heap for leaching.

The thiosulphate leach technology was under consideration for commercial operation at the time the gold price decreased. As a result all work on thiosulphate leaching was put on hold.

Newmont was awarded a patent for its work on thiosulphate leaching of gold.⁴⁹

High pressure grinding rolls technology—the Boddington project

Gold production at the Boddington Gold Mine (BGM) in Western Australia commenced in late 1987 and oxide reserves provided a mine life of 14 years. In the early 1990s work commenced on evaluating the viability of treating the large low grade gold-copper primary resource situated beneath the oxide cap. The primary ore is a combination of competent diorite and andesite and is extremely hard and abrasive.

Over the next 15 years a number of pre feasibility and feasibility studies were undertaken that included extensive SAG and HPGR pilot-plant campaigns for flowsheet assessments as well as extensive diamond drilling and the purchase of the adjacent Hedges Gold Mine to increase the size of the resource.⁵⁰⁻⁵² The lengthy study period was driven by two factors:

- Finding a comminution process to treat the extremely hard and abrasive ore to provide acceptable operating risk and an acceptable project capital cost for the treatment facility. For SAG milling the issues were low throughput rates and 'unacceptable' throughput variability associated with changes in the particle size of the feed. For HPGR the issues related to high wear on the rolls (operating cost and availability) and dust control due to the large amount of fines generated in the HPGR product. A defining point in the evaluation process was Newmont's decision to proceed with a HPGR demonstration plant at the Lone Tree Gold Mine, USA, to evaluate the reliability of new proprietary wear components developed by Polysius.⁵³ The wear components performed exceptionally well during the demonstration period. This result provided the impetus to proceed with HPGR technology for the Boddington project.⁵⁴ The dust issues were resolved with an innovative change to the design of the comminution circuit (i.e. wet screening in the milling circuit as apposed to dry screening in the crushing circuit)
- Developing a resource/reserve base large enough for the low grade deposit to justify the large project capital cost. Extensive drilling of the deposit and the acquisition of the adjacent Hedges Gold Mine provided the resource/reserve base to justify the project economics.

Approval to proceed with detailed engineering and construction of the Boddington Extension Project was given by the joint venture partners, Newmont Mining and AngloAshanti Gold, in February 2006. Construction started in 2007 and commissioning of the treatment plant commenced in July 2009. In February 2009 Newmont purchased AngloAshanti's share of Boddington.

The Boddington comminution flowsheet consists of a primary crushing section, closed circuit secondary and tertiary crushing (with HPGR in the tertiary stage), ball milling and hydrocyclone classification. Nominal treatment rate is 35 Mt/a.

Flash flotation units and gravity concentration of the flotation concentrates are included in the milling circuit. The ball mill cyclone overflow is treated in a flotation circuit that produces a copper-gold concentrate for export. The cleaner scavenger flotation tailings and rougher-scavenger tailings are cyanided leached and gold is recovered in a conventional carbon adsorption circuit (CIL circuit). Final gold recovery is by electrowinning, cathode sludge filtration, drying, and smelting.

Miscellaneous technologies

Improved heap leach operation via Hydro-Jex technology

The large gold heap leach operations in Nevada can suffer low recovery in certain parts of the heap due to 'short circuiting' of leach solutions. Compaction of the heap, excessive fines or clays in the feed and/or heap construction generally create this condition in a heap.

The first challenge for a heap leach operator is to find these areas of low saturation (underleached) or 'dry' zones (unleached). Up until recently the zones of low recovery in a heap were determined by drilling; however, this is expensive and not always a reliable technique. In the last 10 years 3D high resolution resistivity has proven sensitive enough to detect such zones in the interior of heap leach pads and thus enable the 'target' treatment of these zones.⁵⁵

To treat these 'targeted areas' Newmont has adapted a technology from the oil industry (high pressure fracturing technology) that allows leach reagents (e.g. cyanide, lime, etc) to be specifically directed to these 'underleached' areas and recover the gold. The technique is called Hydro-Jex stimulation. The success of re-injecting leach solution can also be evaluated by 3D high resolution resistivity.

The Hydro-Jex process is currently being used at four of Newmont's heap leach pads in Nevada.

Hydro-Jex and 3D high resolution resistivity are tools now available to heap leach operators that can improve metal recovery, change solution chemistry and has the potential to reduce heap 'closure' rinsing time and expenditure⁵⁵.

Preg-robbing test procedure carbonaceous ores

The Standard Preg Test (SPRT) measures the ability of an ore to preg-rob cyanide soluble gold that was developed by Newmont researchers.⁵⁶

'Preg-robbing' is the active adsorption of gold from cyanide pregnant solutions by components of ore. Natural carbonaceous ores and activated charcoal samples are assumed to adsorb gold from solution by a similar mechanism, and have been compared on an organic carbon equivalent basis in an attempt to relate preg-robbing values to the rates of adsorption of gold by active carbon.⁵⁶

For the SPRT test a gold-bearing 'spike' is added to the slurry of ore and cyanide solution. The ratio of gold remaining in solution determines the preg-robbing level. A ratio of 1 would indicate no preg-robbing, while 0 would mean a high preg-robbler. It should be emphasized that preg-rob values are not assays, per se, and that the concept of preg-robbing from a metallurgical standpoint is simply a means of expressing the adsorption capacity of gold from pregnant solutions.

Preg-rob measurements serve to indicate whether a refractory condition may be attributed either to deleterious adsorption of gold values from pregnant solutions or to primary locking.

Thiocyanide leaching of gold

One of the important features of the thiocyanate system is the ability to leach gold in acidic solutions, thus avoiding the problems related to neutralization and material re-handling for gold extraction

One important characteristic of the thiocyanate ion is that it forms stable and soluble complexes of aurothiocyanate, and aurithiocyanate. Under appropriate oxidation conditions, thiocyanate can dissolve gold metal as the aurous complex or the auric complex depending on the thiocyanate concentration and the oxidation potential. Generally, ferric sulphate available from the oxidation of sulphide minerals (e.g. bio-oxidation and pressure leaching) can be employed as the oxidant for gold leaching. Gold leaching in acid thiocyanate solution requires relatively high oxidation. Thiocyanate is not thermodynamically stable under these conditions, however, thiocyanate decomposition by ferric oxidation is very slow in a simple solution. Research has also indicated that in the potential region for gold leaching the sulphide minerals chalcocite, bornite, covellite, enargite, will oxidize.^{57,58}

Laboratory based leaching studies on a number of different ore types have been undertaken to assess the thiocyanide leaching system.

- Thiocyanate leaching of an autoclave discharge sample (head grade 8.4 g/t of gold) collected from one of Newmont's Nevada pressure oxidation plants was tested. Gold extraction in a laboratory stirred reactor after 6 hours ranged from 94 to 97%. Thiocyanate consumption ranged from 0.07 to 0.25 kg/t-ore. For comparison a laboratory cyanidation-CIL bottle roll test yielded 96% gold extraction
- In another laboratory evaluation, a bio-oxidized ore from Carlin was column leached for 16 days and results compared to a standard Newmont cyanide column leach test. The gold extraction from the two acidic thiocyanate leach columns were similar at around 52% which was 10% higher than that obtained from the cyanide leach column. The cyanide consumption was 0.3 kg/t of ore while thiocyanate was double this quantity
- Recently, thiocyanate leaching of an oxide ore was evaluated using stirred reactors in laboratory experiments. The oxide ore contained 9.8 g /t of gold and 0.09% sulphur. Gold extractions ranged from 95% to 97% after six hours which compared to 94% gold extraction from cyanidation after 24 hours. Thiocyanate consumption ranged from 0.14 to 0.43 kg/t ore.

The results indicate that thiocyanate is much more stable in the leaching of oxide ores than in the leaching of sulphide ores.

Test work to evaluate ways to recover the gold from the acidic thiocyanate leach solution suggest that both tertiary amine solvent extraction followed by stripping of the gold from the loaded organic phase with thiourea or adsorption onto activated carbon are viable options but require more detailed assessment.

A provisional patent has been applied for the thiocyanate leach process.⁵⁹

Summary

Newmont's existence over the last 93 years can be traced to two factors. The first relates to the ability of its management to change the company's strategy and style at the appropriate time to meet the cyclic nature of the mining business. The second relates to Newmont's technical strength to develop new technologies to discover new ore deposits and also technologies to mine and process the metals in these deposits.

Gold has played an important part in Newmont's development, starting with the investment in Anglo American in 1925, followed by a survival strategy in gold mining during the depression years and lastly over the last 50 years the development of large gold mines around the world using in-house innovations.

Undoubtedly there are going to be bigger challenges in the future that will encompass finding new viable gold deposits, the development of viable mining and processing technologies that are able to treat more complex ore deposits and last but not least dealing with more stringent environmental legislation.

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