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Cold climate heap leaching

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Abstract

Heap leaching is no stranger to extreme climates. Heap leaching is often carried out at high altitudes, or at extremely arid or wet sites. It is less well known that heap leaching operations are carried out successfully in cold climates. The authors surveyed 28 projects located in cold regions, ranging from the southern Andes to Alaska, Yukon Territory to Mongolia. The authors used data from direct discussions with operators and engineers, reviews of published literature, and personal experience to compile operating statistics for some 210 million tonnes per annum (Mtpa) of heap leach production, with leaching rates ranging from under 1 to 30 Mtpa. The severity of the winter months are quantified in two ways: the average daily temperature for the coldest month, and the length of the cold season as measured by the number of months per year with an average daily temperature below zero for an average year. Of the sites surveyed, the coldest months average –18.1°C and range from –6°C to –31°C, and the length of the cold season ranges from 4 to 10 months. The coldest temperatures are found at the Russian sites, while the longest winters are experienced in the southern Andes. Conventional leach pads are used at the majority of sites (57%) while dynamic heaps (on/off leach pads) and impounding valley leach pads are used by 28% and 18% of the sites, respectively.

Introduction

As the demand for various metals has increased beyond that which can be met by processing easily available, higher-grade ores, and as heap leaching technology has advanced to accommodate the increased demand, the number of heap leaching operations around the globe has increased. A world map of major heap leach projects and operations (Infomine, 2013) shows a little over 300 facilities in various stages of development, ranging from pre-feasibility to fully operational. These facilities include gold, copper, silver, nickel and uranium operations, and some of these have dual circuits for recovering other commodities like molybdenum, zinc and lead. Many of these facilities are in cold climates with average temperatures for the coldest month ranging from –6°C in the continental US to –31°C in the Russian Arctic. Such temperatures and harsh weather conditions create some operational challenges not faced in more temperate climates. This paper attempts to address these challenges, though the operational details of these facilities, especially in Asia, are often scant and scattered.

Purpose and methodology

An earlier paper divides cold weather heap leaching into two basic regions: Arctic and sub-Arctic, defined as above the Arctic Circle (approx. 67^0N) and below the Arctic Circle down to approximately 45^0N latitude, respectively (Smith, 1997). However, some heap leach operations in the high Andes in the southern hemisphere as far north as 30^0S latitude also have sub-Arctic-like climates (Smith, 1996). Out of the 300-plus heap leach operations shown on the Infomine (2013) world map, about 70 are in the Arctic and sub-Arctic regions as so defined. Cold climate operations require unique design and operational considerations. These range from seasonal operations, maintaining heat within or adding heat to the heap, permafrost management, leaching kinetics (especially for bioleach operations), managing ice and snow, and closure. In a sense, this is a benchmarking paper meant to assist in the decision-making process for owners, engineers, reviewers and regulators. It can as well serve as an inducement or vehicle for others to build upon this public database with additional relevant information, experience and insights.

In spite of the fact that there are some 70 heap leach facilities planned or operating in sub-Arctic or Arctic regions, and that several international symposia on "mining in the Arctic" have taken place since the first one in 1989, not much has been published in the form of technical papers on the issues specifically related to cold-climate heap leaching. A noteworthy technical paper giving some insight into the operational methods was published 18 years ago (Smith, 1997). Kappes (2002), in his informative paper on heap leaching design and practice in general, also sheds some light on cold-weather issues. In a recent short paper, Kashuba and Leskov (2014) provide an overview of the history of heap leaching in Russia, along with some lessons learnt and how these are influencing a new surge of operations there. By and large, the operational and production data for specific cold-weather heap leaching operations are scattered over the mining companies' web sites, some pre-feasibility, feasibility or NI43-101 reports, and various environmental filings. For many of the Asian mines, unless owned, operated or otherwise affiliated with a western mining company, little data is publically available. The information presented in this paper has been extracted from all of the sources just described, in some cases interviews and correspondence with operators and engineers, and from the authors' own files (for brevity, not all of these sources are included in the reference list).

A total of 28 cold climate projects have been included in the present study. These operations are located on the European, Asian, North and South American continents. The Asian operations include mines in Russia, Kazakhstan, China and Mongolia. The South American mines for which some information could be gathered are in Chile and Argentina. The North American mines are from Alaska, Montana and South Dakota in the US and in Yukon Territory in Canada. A single cold-climate operation was identified in Europe, the Talvivaara Nickel Mine in Finland. Table 1 gives some overall statistics of the facilities included in the study.

Table 1: Summary of cold-climate heap leach operations

Description	Number of operations	Percentage of total number
Total number of operations included in the study	28	100%
Heap leach pad type:		
Conventional (*)	16	57%
Dynamic or on/off	8	28%
Impoundment valley fill	5	18%
Metal mined:		
Gold	24	86%
Copper	3	11%
Nickel	1	4%
Year-round stacking	12	43%
Year-round irrigation	16	57%

* One mine uses both conventional and dynamic pads, hence included in both categories

Tables 2, 3 and 4 provide some specific data for the projects in the Americas, Russia and other Asian countries, respectively; the lone European project is included in Table 3. Each of these sections also includes some geographical, production and additional climatic details of the listed mines. An effort is made to avoid repetition of information between the tables and the individual mine descriptions. The temperature data, where not available for the actual site, has been obtained for the nearest weather station found in the world almanacs.

The following notes refer to these tables:

- Status: (op)erational, (s)uspended, (c)losed, (p)lanned,
- Heap type: (C)onventional, (V)alley leach pad, (I)mpounding VLP, (D)ynamic (on/off)
- Ore grade and production statistics: average of last 2 or 3 years where applicable. Where the plant has dual circuits, grade for the HL ore may have been estimated from other data.
- Ore stacking: Seas = seasonally; most of the Russian heap leach facilities have been reported to use dynamic or on/off leach pads and operate seasonally (Kashuba and Leskov, 2014).
- Climate data: Ave Temp = Average Temperature; est = estimated

North and South American mines

Table 2 presents the data for the heap leach projects in the Americas, and a discussion of each project provides more detail.

Fort Knox (Walter Creek) Mine, Alaska

Fort Knox Mine (owned by Kinross Gold), located approximately 26 miles northeast of Fairbanks, Alaska, operates both a conventional mill and an impounding valley fill heap leach facility centered at approximately latitude 65° 0.76N, longitude 147° 20.92W. The heap leach pad has a capacity of 160 million tons, and an in-heap storage pond, covering an area of 124 hectares. The mine has a typically cold and dry sub-Arctic climate with a mean precipitation of approximately 46 cm, with recorded low temperatures of down to –62°C. Ore is mined throughout the year and stockpiled in winter. The ore cut-off grade for heap leaching is 0.17 gpt. The leach pad is stacked late March to late November only and the leaching continues with a 90-day leach cycle on ore stacked in 15 m thick lifts. Nominal production is 30 Mtpa of heap leach ore. Pregnant solution temperatures range from 2° to 8°C. The average irrigation rate is 9.6 $L/h/m^2$ with 371,672 m^2 under leach. The ultimate heap height will be 153 m (measured vertically over the liner).

Basin Creek Mine, Montana

Commissioned under ownership of Pegasus Gold in 1989 and operated until 1991, this conventional heap leach operation was located near Helena, Montana. In that short period, gold production ramped up to approximately 26,500 ounces per year. The monthly average low temperature at the site ranges from approximately –11°C in January to 12°C in July, with sub-zero average temperatures for 7 months annually.

Gilt Edge Mine, South Dakota

The Gilt Edge open pit mine (owned and operated by Brohm), located 10 km from Deadwood in the Black Hills of South Dakota, was commissioned in 1988 and operated until 1999, producing 4.1 Mtpa of ore with an average grade of 1.5gpt, at a strip ratio of 2.1:1. Crushed ore was stacked on an on/off leach pad (dynamic heap). The original leach pad was double lined, with a primary liner of asphaltic concrete with a layer of bitumen-impregnated geotextile in the middle. This leaked in excess of the allowable rates and a geomembrane liner was installed over the asphalt. Barren solution was heated using a direct-fire system. The average monthly low temperature ranges between –12°C in January to 12°C in July and remains sub-zero for 7 months annually.

Wharf Mine, South Dakota

Wharf open pit mine (owned by Coeur/Royal Gold) is located near the Gilt Edge mine, outside of Deadwood, South Dakota. The plant and mine have been operational since 1986, with an idle period in the early 21st century. The mine is currently producing approximately 3 Mtpa of ore at an average grade of 0.74 gpt. The mine has a conventional leach pad and is producing 85,000 to 90,000 ounces of gold annually. The monthly average temperatures and the precipitation are the same as indicated for the Gilt Edge mine site.

Casino Copper-Gold Mine, Yukon Territory, Canada

The proposed Casino Project (owned by Casino Mining Corp/Western Copper and Gold) is a planned open pit mine in the Dawson Mountain Range of the Klondike Plateau, approximately 300 km from Whitehorse. Sulfide and oxide ores will be mined and processed by conventional concentration and heap leaching-SX/EW, respectively. The heap leach facility will use an impounding valley fill pad with a buttress and external events pond. No barren solution heating is discussed in the sources searched, but after the first 3 years the heap leaching facility will have the advantage of the thermal mass of the mill and tailings facility. The design footprint for the leach pad is 1.5M sq. m. with a total in-heap storage capacity of 172,600 m^3. The life of heap leach operation is 18 years. The average annual temperature for the Casino Project area is –3°C with monthly average minimum and maximum temperatures being –17°C in January and 12°C in July, respectively. Extreme maximum and minimum temperatures recorded over a period longer than 100 years are 35°C and –60°C, respectively. Most of the precipitation falls in the form of snow during the months of November through March, and in the form of rain during the months of May through September. Stacking of heap is planned for 300 days/year in 8m lifts, with year-round irrigation using buried irrigation lines.

Brewery Creek Gold Mine, Yukon Territory, Canada

Brewery Creek gold project (Viceroy Minerals), located approximately 55km southwest of Dawson City, was operated as an open pit mine and a heap leach facility. The mining and construction started in 1996 with 190,000 tons of ROM ore placed on 15.8 hectares of pad in the first year. This was expanded to 38 hectares in a four-year ramp-up period. Drip irrigation lines were ploughed into the heap 0.6 to 1 m deep with the headers buried in ditches such that the collected snow acted as heat insulators. Piping was also heat traced. Waste heat from generators was used to heat up the barren solution. Mining and ore stacking were 7 months per year, with year-round irrigation. Active mining stopped in the year 2000 and no more ore was placed on the leach pad. Leaching ceased after December 2001. Between 1.4 and 2.6 Mt of ore were placed on the leach pad. Local temperatures average –0.6°C annually, with the coldest month (January) averaging –19.0°C (for the period of 1991 to 2010); January low temperatures ranged between –30.0°C and –46.0°C.

Eagle Gold Mine, Yukon Territory, Canada

Victoria Gold Corp's proposed Eagle Gold project will be an open pit mine and a valley heap leach facility with in-heap pond storage capacity of 459,349 m^3. Production and processing is estimated to be 10.7 Mtpa of ore after ramp up with a 10-year life. Gold recovery is forecast at 72.6% with gold production averaging 212,000 ounces per year for the first five years, followed by 192,000 ounces per year. Crushed ore will be stacked on the leach pad in 10 m lifts for 250 days per year and leaching will continue year-round with a leach cycle averaging 150 days. Drip lines will be buried 3 m deep in the heap and barren solution will be heated in the winter "as required." The maximum and minimum recorded temperature at a weather station on site over a three-year period (2007 to 2009) was 26.9°C and –36.5°C in July and January of 2009, respectively. The average annual temperature on site is approximately –3°C. The estimated mean annual precipitation in the study area ranges from 389 mm to 528 mm depending on the elevation.

Table 2: Operational and production details – North and South American mines

Mine name, status	Heap type	Metals produced, HL ore grade	HL production statistics			Climate data	
			Tonnage, recovery	Ore stacking d/y	Irrigation (d/yr)	Months with ave temp <0°C	Ave temp for coldest month, °C
Fort Knox, AL, USA (op)	I	Au	30 Mtpa 65%	250	365	6	–22
Basin Crk, MO, USA (c)	C	Au	1 Mtpa	365	365	4	–6
Gilt Edge, SD, USA (c)	D	Au 1.5 gpt	4.1 Mtpa	365	365	4	–6
Wharf, SD, USA (o)	C	Au 0.74 gpt	3 Mtpa	365	365	4	–6
Casino, YT Canada (p)	I	Au 0.29 gpt	8.8 Mtpa	300	365	7	–16
Brewery Creek, YT, Canada (s)	C	Au 0.77 gpt	<1 Mtpa 62%	210	365	6	–19
Eagle, YT, Canada (p)	I	Au 0.78 gpt	10.7 Mtpa 72.6%	250	365	7	–24
Coffee Gold, YT Canada (p)	C	Au 1.23 gpt	5 Mtpa 88%	285	365	7	–22
Veladero, Argentina (op)	I	Au 1.00 gpt	29.5 Mtpa 77%	365	365	10	–14
Maricunga, Chile (op)		Au 0.72 gpt	17 Mtpa 85%:ox 69%: Su	365	365	5 est	–10 est
Cerro Maricunga, Chile (p)	C	Au 0.40	29 Mtpa 76%	365	365	5 est	–10 est
Collahuasi, Chile (op)	C	Cu 0.83%	13 Mtpa	365	365	4 est	–7 est

Coffee Gold Project, Yukon Territory, Canada

The Coffee gold project (owned by Kaminak Gold Corporation), is located within the Whitehorse Mining District of west-central Yukon, 130 km south of Dawson city. The Project is to involve open pit mining and a conventional leach pad with the pregnant and barren solutions stored in and supplied directly from the tanks. Current plans are to process ore at the rate of 5.0 Mtpa ore, with the ore stacking on the heap limited to 275 days during the year and irrigation all through the year. The solution will be heated in the cold season using waste heat from the generators and some additional boilers. Drip irrigation lines are to be buried during the cold season and raincoats will be used to shed surplus water and aid heat retention. According to the June 2014 Preliminary Economic Assessment, planned total production over a 12-year mine production life is 53.4 Mt of heap leach feed and 212.4 Mt of waste (4:1 overall strip ratio)

Veladero Gold Mine, San Juan, Argentina

Barrick Gold's Veladero open pit gold mine with an impounding valley fill leach pad facility is located at an elevation of 4,000 m near the Argentina-Chile border and adjacent to the Pascua-Lama gold project. Impoundment in leach pad is held to a minimum, however, to reduce flows to the LCRS/pump-back system and resulting regulatory oversight (Barrick, 2014). There is also an external pond that can be used for either events or pregnant solution. The ore mining and stacking rate has ramped up from approximately 17 Mtpa at start up in 2005 to 29.5 Mtpa in 2014, with an average grade of 1.0 gpt and 77% recovery. Ore is mined and stacked on the heap all year with no seasonal breaks. Waste heat from ten 1-MW generators are used to heat barren solution and a waste oil burner is also available but no longer used. The heap is irrigated continually to avoid drain down (and the resulting surplus water). Drip emitters are ploughed in at 150 mm depth, principally to keep them out of the strong winds. Winter operations include two new cells stacked and with all irrigation piping in place, ready to be brought on-line if an active cell of similar surface area becomes frozen. The pregnant leach solution temperature remains consistently in the 7^0 to 12^0C range, largely due to a build-up of a large heap thermal mass over time. The site can be subject to freezing temperatures at night throughout the year. During the winter months (April-September) the lowest temperature can go below –20^{0}C and are typically around –10^{0}C.

Maricunga Gold Mine, Chile

The Maricunga Gold Mine, formerly known as Refugio Mine (owned by Compañía Minera Maricunga/Kinross) is located in the Maricunga Gold Belt in Region III of northern Chile, at elevations between 4,200 m and 4,500 m above mean sea level, and 120 km due east of the city of Copiapó. The mine operated from 1996 to 2001, producing more than 920,000 ounces of gold from 46 million tonnes of ore. Full production resumed in late October 2005 and continues as of this writing. The mine operates with two gold deposits, Verde and Pancho, in the Maricunga Gold Belt. In 2007 it was decided that only the Pancho ore will be processed. The mine plan called for a rate of approximately 49,000 tpd over the life of mine with the expected average heap leach gold recovery of 85% for oxide ore, 75% for mixed ore and 69% for sulfide ore. The average minimum temperature for a nearby weather station over an extended 30-year period (1960 to 1990) was –1^{0}C. At an elevation of 4,000 m, local temperatures range between –30°C at night in the winter months to 20°C during the summer months. Precipitation averages 87 mm/yr.

Cerro Maricunga Gold Mine, Chile

This mine (owned by Atacama Pacific) is in advanced planning stage and is located 60 km north of the Maricunga mine owned by Kinross. A conventional heap leach pad is planned to process 29 Mtpa of crushed ore. Ore reserves (proven and probable) total 294.4 Mt at 0.4 gpt Au. A 13-year mine life is forecast, and gold production will begin in 2016 with projected recovery of 76 to 79%. Climate at Cerro Maricunga is similar to the nearby Maricunga mine.

Collahuasi Copper Mine, Chile

Collahuasi copper mine (owned by Xstrata, Anglo American and a Japanese consortium), is located in the Andean plateau 4,400 meters above sea level in the Tarapacá Region in northern Chile, approximately 180 km southeast of the port of Iquique and close to the border with Bolivia. The mine was commissioned in 1999 and an expansion project was completed in 2004, giving the plant a capacity of producing 500,000 tpa copper via both a conventional concentrator plant and a heap leach-SW/EW circuit. In 2005, the company commissioned a molybdenum recovery plant with a capacity of 7,500 tpa of contained molybdenum. The mine ownership has changed over the years and currently a Chilean mining company, Doña Inés de Collahuasi, operates the mine. The operation comprises of two principal porphyry copper deposits, Ujina and Rosario, and a smaller deposit called Huinquintipa. Both oxide and sulfide ores are mined and processed. Oxide and mixed ores are treated by heap leaching and electro-winning (SX/EW), while the sulfide ore is crushed, ground and treated by flotation. Although, the lowest average monthly temperature over the extended past of 30 years is a relatively moderate 2°C, the actual low temperature during the winter months often falls as low as –30°C. Generally, the operation continues throughout the year, but there have been instances of severe weather-related impacts on production.

Russian and European mines

Table 3 presents the data for the Russian and one Finland mines in the same way as Table 2 does for the mines in the Americas. Figure 1 shows a portion of the world map of heap leach facilities (InfoMine, 2013). The Russian, Mongolian, Kazakhstani and Chinese mines included in the present study are marked on the map with red ellipses to provide a visual sense of the mines' absolute and relative locations. Talvivaara Nickel Mine, Finland

The Talvivaara project (owned by Talvivaara Mining Company, Plc), located approximately 64°N latitude, near the town of Sotkamo in eastern Finland, started operation in 2005 to process nickel sulfide ores. A two-stage leaching system is used, with biological treatment occurring in a dynamic heap as state 1, and solvent leaching on a conventional heap as stage 2. The target production is 30,000 tpa nickel and byproducts of cobalt and zinc. The average monthly low temperatures at the site range from 11°C in the summer to –19°C in the winter, with extremes dipping to below –45°C. Ore stacking is seasonal with different stacking schedules for the bioleach and conventional heaps and irrigation is year round.

Voro Mine, Russia

Located in the Sverdlovsk Region/Russian Urals of Central Russia, the Voro mine (owned by Polymetal International), was acquired by the current owner in 1988 and has been producing since 2000. Primary and oxidized ores are mined in two pits, 240 m and 80 m deep. The deeper resource is processed by conventional heap leaching and the other in a carbon-in-pulp (CIP) plant. The CIP plant has been running almost at its full capacity of 950 ktpa since production started and the heap leach pile is to reach its full design height in 2015. Mine life is expected to be until 2027. The daily average low temperatures in the coldest and hottest months at nearby city, Serov, are –24^{0}C and 11^{0}C, respectively.

Neryungri Mine, Russia

Neryungri mine (owned by Nordgold) is located in Tabornoe gold deposit at an elevation of 1,100m to 1,300 m above sea level in the southwestern Sakha (Yakutia) Republic in Russia, approximately 200 km from the town of Chara. Production started in 2010 and the current mining license is valid till 2020. Low-grade oxidized ore is crushed and leached on a heap leach pad in two lifts, the leach cycle for fresh and the bottom lifts being 60 days and 120 days, respectively. A second leach pad is to be constructed in 2015. The ground is snow-covered from October to May, with the frozen ore on the pad restricting penetration of leaching solution and the permafrost extending to approximately 400 m depth below. Accordingly, the majority of crushing and stockpiling of ore occurs from May to September, and leaching from July to December.

Aprelkovo Mine, Russia

The Aprelkovo gold deposit (Owned by Nordgold) is situated amidst rolling hills at an elevation ranging from 580 m to 665 m amsl in the Shilkinskii district of Russia, approximately 120 km east of the regional center, Chita. Historically, production has been from oxide and, more recently, from transitional ore types, using heap leaching with gold recoveries of 57% and 64%, respectively. Both of these ore types have now been exhausted and as an interim measure, primary ore is being treated, with gold recoveries reduced to approximately 46 to 48%. The climate is extreme continental with a long winter and short, hot summer. The maximum and minimum temperatures during the year are typically +37°C and –46°C, respectively, with the annual average of –1.6°C. Annual precipitation is in the range of 300 mm – 600 mm, with most of it falling in August.

Table 3: Operational and production details – Russian and Finland mines

Mine name, status	Heap type	Metals produced, HL ore grade	HL production statistics			Climate data	
			Tonnage recovery	Ore stacking d/y	Irrigation (d/yr)	Months with ave temp <0°C	Ave temp for coldest month, °C
Talvivaara Mine (op)	D/C	Ni 0.24%	11.1 Mtpa 66%	210	365	7	−12
Voro Mine (op)	D	Au 1.47 gpt	0.83 Mtpa 74.2%	Seas		5	−19
Neryungri (op)	D	Au 0.92 gpt	3.5 Mtpa 75%	Seas		7	−31
Aprelkovo (op)	D	Au 1.11 gpt	2.27 Mtpa 57–64%	Seas		5	−24
Omolon Hub (op)	D	Au 1.1 gpt	1 Mtpa	Seas		7	−19
Berezitovy (op)	C	Au		Seas		7	−26
Pioneer (op)	C	Au		Seas		6	−24
Pokrovskiy (op)	C	Au	0.80 Mtpa	Seas	365	6	−25
Savkino (op)	C	Au 2.0 gpt	0.5 Mtpa 86.4%	180	365	5	−24
Staroverenskaya and Tardan (op)	D	Au 1.36 opt	0.35 Mtpa	Seas		5	−28
Chazy-Gol (p)	D	Au		Seas		5	−15
Kuranah (op)	C	Au	3.8 Mtpa	Seas		7 est	−25 est

Figure 1: Map showing the heap leach facilities in Russia, Kazakhstan, Mongolia and parts of China (InfoMine, 2013)

Omlon Hub Mine

Omolon hub (owned by Polymetal International, Inc.), is located in remote unpopulated areas in the northeast of the Magadan region. The hub was created in 2009 and now includes 4 operating open pit mines (Birkachan, Sopka Kvartsevaya, Tsokol and Dalneye) and a few development projects with high-grade ore conducive to open-pit mining and significant long-term potential. Of these only the low-grade ore produced at Birkachan pit (followed by underground mining until 2023) has been heap-leached in the past. In 2013, Polymetal decided to suspend mining at Birkachan site for 9 months and defer the start of heap leaching at Birkachan for one year. It is not clear if heap leaching has resumed at Birkachan, but it is expected to start at the Sopoka site of the hub in 2016.

Berezitovy Mine, Russia

The Berezitovy gold mine (owned by Petropavlosk) is an open pit operation, located in the far-east Amur region of the Russian Federation. Originally, the processing was done through milling and CIP circuits, but in late 2012 the mine expanded operations to include a heap leaching facility to treat low-grade ore. The ore mineralization is polymetallic sulfides with silver, zinc and lead by-products. Known reserves can take the operation to continue for at least eight more years.

Pioneer Mine, Russia

Pioneer mine (owned by Nordgold/Petropavlovsk Group) is the Group's flagship mine, producing about 42% of its total gold production in 2013. One of the largest gold mines in Russia, Pioneer is located in the Amur region, Russian Far East, 40 km to 60 km from the towns of Tigda and Zeya. The mine was acquired as a green field deposit in 2001 and finally commissioned in 2008 with dual-circuit processing facility: a resin-in-pulp (RIP) plant and a seasonally operating conventional heap leach pad. The RIP plant has since undergone three expansions, enabling the cost-effective processing of bulk tonnage, lower grade ores from across the mine site. The plant now has a processing capacity of 6.0 Mtpa to 6.6 Mtpa and produced 314,850 oz of gold in 2013.

Pokrovskiy Mine, Russia

Pokrovskiy (owned by Petropavlovsk Group), is a hard-rock open-pit gold mine located in the Amur region, Russian Far East, approximately 35km from Pioneer mine. Pokrovskiy produced its first gold from its heap leach facility in 1999. In 2002, its RIP plant was commissioned. To date, more than 1.85 Moz. of gold has been recovered from Pokrovskiy mine and the end of mine life is drawing close. With the original pit at the Pokrovka-1 deposit almost depleted, mining has been gradually shifting to satellite deposits of Pokrovka-1.

Savkino Gold Project, Russia

White Tiger's Savkino project is an open-pit gold mine producing 500,000 tpa of ore with a conventional heap leach pad and an ADR plant, located 400 km east of Chita in the Zabaikalsky Province of South Siberia. Crushing, agglomeration and stacking operate for six months per year, from spring to autumn, on a 16-hour, two-shift basis. Heap leaching and ADR are designed for continuous 24 hours/day operation, 365 days/year. The leach cycle consists of 10 days of wetting with dilute cyanide solution followed by up to 60 days leaching. The ore mined so far comprises of: 66% Oxide; 11% Transition; 12% Primary (11% is un-estimated) and the actual recovery is characterized as: Oxide >72%; Transition 52% to 72%; and Primary <51%. The monthly average lowest and highest temperatures are reported as –30°C in January and 25°C in July. Extremely bad weather in 2011 negatively impacted heap kinetics for an extended period and resulted in the drop in production.

Tardan/Staroverenskaya, Chazy-Gol and Kuranah Mines, Russia

The Tardan Mine (owned by Central Asia Gold/Auriant Mining), heap leached 123,600 t of crushed ore with grade 1.57 gpt and produced 229 kg of gold in 1st half of 2014, almost double the production in the first half of the previous year. In the same time frame, Staroverenskaya mine processed 49.6 Kt of ore at grade 0.83 g/t and recovered 28.1 kg of gold. The Chazy-Gol Mine (owned by Auriant Mining/Golden Star Co.) is located approximately 34 km from the town Askiz in the Khakass region. It is a producing mine with on-going heap leaching exploration. There is well-developed infrastructure in the region with many gold producers nearby. Located in the Sakha Republic (northeast Siberia), the Polysgold's Kuranah mine produced 137,000 ounces in 2014, 100% from heap leaching. According to their latest annual report, the mine processes 3.8 Mtpa of ore.

Other Asian mines

Table 4 presents the data for mines in China, Mongolia and Kazkhstan, followed by more details for each operation.

Aktogay Copper Mine, Kazakhstan

This project is owned by Kazakhmys and will heap leach 120.5 Mt of copper ore grading 0.37% average. Ore will be processed as run-of-mine with a relatively fine particle size (P80 = 80 mm). Following sulfuric acid heap leaching on a conventional leach pad, copper will be extracted by conventional SX/EW circuits. Copper mineralization is principally chrysocolla, aktogayite, atacamite, malachite and cuprite. The cold climate is accommodated through some special provisions including insulated or buried pipes and valves, heated raffinate, thermal covers on the heap, buried drip lines, floating balls in ponds, and backup generator power to avoid pump down time.

Table 4: Operational and production details – mines from China, Mongolia and Kazakhstan

Mine name, status	Heap type	Metals produced: HL ore grade	HL production statistics			Climate data	
			Tonnage recovery	Ore stacking (d/yr)	Irrigation (d/yr)	Months with ave temp <0°C	Ave temp for coldest month, (°C)
Aktogay, Kazakhstan (c)	C	Cu 0.37%	12.0 Mtpa 48.1%	365	365	6	−14
Chang Shan Hao, China (op)	C/I	Au 0.6 gpt	21.9 Mtpa 65.6–80%: Ox 24.6–70%:Su	365	365	5	−13
Boroo, Mongolia (s)	C	Au 1.04 gpt	2.1 Mtpa 57.6–72.9%	365	365	5	−24
Erdmin, Mongolia (op)		Cu				5	−24

Chang Shan Hao (CSH) Gold Mine, China

The CSH gold mine (China Gold International Resource Corp) is one of China's largest gold mines. The project is located on the Inner Mongolian Plateau, approximately 210 km northwest of the city of Baotou, at an average elevation of 1,550 m to 1,750 m above sea level. The mine site has a typical continental interior climate in semi-desert conditions. The summers are dry and comfortable with temperatures rarely exceeding 30°C. The winters (early October to mid-March) are cold and windy with monthly average lows down to –20°C. Annual rainfall averages 230 mm, principally falling between July and September. The facility includes a conventional open pit mine and heap leaching operation, and the principal products are doré bars. Original ore processing capacity was 30,000 tpd, but an expansion project began in 2012 to build capacity to 60,000 tpd. The facility has 2 leach pads which vary in maximum heap height from 90 to 120 m. Phase 1 is a conventional or flat leach pad with external pregnant solution pond, while Phase 2 is a hybrid between a conventional and a valley leach pad which partially impounds solution. Gold recovery is forecast at 65.6% to 80% for the oxide ore and 25.6% to 70% for sulfides.

Boroo Gold Mine, Mongolia

Centerra Gold's Boroo Mine is located approximately 250 km west-northwest of Ulaanbaatar, the country's capital. The gold deposit extended over a 2.5 km by 1.5 km flat-lying area with a series of mineralized zones up to 400 m wide and 10 to 30 m average thickness. The facility had a standard layout consisting of crushing, grinding, gravity concentration, cyanide heap leaching and gold recovery in a CIL circuit. The plant was designed with a capacity to process 1.8 million tonnes of ore per year, but the actual mill throughput was approximately 2.1 million tonnes per year. Boroo began commercial production on March 1, 2004. Mining was suspended in 2010, resumed briefly from January to September 2012, but the operation continued to mill lower grade stockpiled ore, producing 53,128 Oz of gold in 2014. In December 2014, the processing of the stock piled ore was completed, and during 2014 the mine produced approximately 1.8 MOz of gold.

Erdmin Copper and Molybdenum Mine, Mongolia

The Erdmin copper-molybdenum mine (owned by Eardnet Minerals Solution), located in the northern region, approximately 400 km northwest of the Mongolian capital, Ulaanbaatar, is the largest mine in Mongolia, and has been operational since 1978. A heap leach-SX/EW plant was commissioned in 1997 to process low-grade oxidized ore as an experiment. Since then, the mine has been operating year-round at its name-plate capacity, producing 3,000 tonnes of copper cathode annually, establishing the viability of heap leach technology in Mongolia's winters. During the winter, the company drills holes deep into the heap and injects dilute sulfuric acid to prevent freezing. In 2009, a new SX/EW plant with a capacity of producing at least 50 tonnes of copper cathode per day was under study. The status of this expansion is unknown.

Summary

Cold-climate heap leaching is relatively common and has seen good success. There are approximately 70 heap leach projects in the Arctic, sub-Arctic, and sub-Arctic-like climate zones in the Andean mountains. The authors researched 28 of these and various operating and design statistics are presented in the Tables 1-4, above. Some of the projects studied have been in operation for 15 or more years, suggesting sustainability and profitability. Some lessons learned from these operations are:

- Ore temperature being close to the average daily temperature when it is stacked, winter ore stacking creates a heat sink in the system. Successful winter stacking in very cold climates requires provisions such as: increased solution heating, ore temperature monitoring, thermodynamic modeling, and a relatively large thermal mass. Also, large snow and ice inclusions in the heap during winter stacking can create ice dams and promote heap freezing.
- Operational problems during the first one or two winters after commissioning are relatively common, suggesting that additional measures should be implemented (such as solution heating) until the heap has a larger thermal mass.
- Exposed ponds can freeze in winter and special provisions are required to protect liners and avoid water shortages during stepped-up demand when ore stacking resumes in spring. On the other hand, impounding VLPs are inherently more likely to leak and create compliance issues (Breitenbach and Smith, 2012).
- Average temperature-based planning (which is generally the case) can require operational adjustments such as additional solution heating, deeper dripper burial, and a shorter stacking season, to accommodate colder-than-average temperatures.

- Although there are successful impounding VLPs and dynamic heaps, the industry seems to prefer conventional pads (57% of surveyed installations). This may be partly for economic reasons as conventional pads are less expensive than VLPs (Smith and Parra, 2014), and party due to liner leakage and compliance issues inherent with in-heap solution storage.
- For year-round irrigation, insulating and heat tracing or burying all piping including drip lines (at depths dependent on site conditions) may be necessary. Providing spare irrigation area(s) for the coldest sites in case primary drip areas freeze is a good idea. Seasonal irrigation requires pond capacity for the seasonal drainage of the heap.
- Seasonal barren solution heating in the colder climates for at least the first 2 or 3 years might be necessary until the thermal mass becomes sufficiently large; boilers and waste heat from generators have been used in many cases.
- It is unknown whether the mixed success of the only bio-leaching operation included in the study, Talvivaara in Finland, is cold-climate related or due to the extremely low grade ore and declining nickel prices.

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