The Application of Ore Sorting Technology at Anglo Asian Mining's Gedabek Gold Mine in Azerbaijan

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ABSTRACT

Anglo Asian Mining has installed a 100 t/h ore sorter equipped with multi sensor XRT technology at its copper-gold mining operations in Gedabek, Azerbaijan. The equipment was commissioned in the second half of 2021 and a number of test campaigns were carried out on different ore types from both underground and open pit operations. The Gedabek ore types are classified geometallurgically and treated by one of four process routes, namely: crushed ore heap leaching; run-of-mine heap leaching; agitation leaching; flotation.
The test results at industrial scale showed that the best economically viable performance of ore sorting at Gedabek is for pre-concentration of flotation feed ore from the open pit mine and that the ore sorter performance depends primarily on density differences between the mineral-containing and barren rock particles. For each type of ore there are several machine parameters that have to be optimized to achieve best performance.

1. INTRODUCTION

In May 2009, Anglo Asian Mining, a London-listed, junior gold mining company, started operations at its first mine, which it had developed near a remote town called Gedabek, high in the Lesser Caucasus mountains in western Azerbaijan. Not only was this mine the junior company's first mining operation, it was also the first metal mine to be built in Azerbaijan for over a century. In the second half of the nineteenth century, Gedabek had previously been a mining town, when the Siemens company from Germany operated a copper mine there for about 50 years, until the Russian revolution intervened after the end of the First World War, when the Germans closed the mine and returned home. By then, oil had been discovered in Azerbaijan, both on-shore and off-shore in the Caspian Sea, and so the country rapidly became an important source of energy for the growing industrial demands of the USSR. During the Soviet era, mineral exploration continued in the Gedabek region, but no further mining development took place during the rest of the twentieth century, until Anglo Asian began operating its new open pit gold mine early in the new millennium, using state-of-the-art ion-exchange processing technology to produce 50,000 oz of gold per year.

2. DEPOSIT DESCRIPTION

2.1 Regional Geology

Azerbaijan straddles the mountain ranges of the Greater and Lesser Caucasus, which are part of the Alpine-Himalayan mountain chain that marks the collision of the African and Indian continental plates with the Eurasian plate. The continental collision is manifested by the Alpine tectono-magmatic cycle, which shows a progressive development from predominantly oceanic magmatism in the Jurassic, through to predominantly continental magmatism in the Tertiary. This magmatic episode was responsible for one of the world's major metallogenic belts, the Tethyan, which can be traced from Pakistan, through Iran, the Caucasus and Turkey, to the Balkans. Notable deposits within this belt include a spectrum of hydrothermal deposit types ranging from Cyprus-type massive sulphide deposits, through porphyry copper and gold deposits, to epithermal gold deposits.

2.2 Local Geology

The Gedabek deposit lies on the Tethyan belt in the Lesser Caucasus mountains in western Azerbaijan at an altitude of 1600m, close to the border with Armenia and about 60km from Ganja, Azerbaijan's second city. The deposit exhibits many characteristics typical of porphyry copper-gold deposits, but it is peculiar in the development of distinct bodies of massive and semi-massive sulphide, as well as the more normal porphyry-style disseminated and stockwork mineralization.

The Gedabek deposit is believed by Azeri geologists to be a composite ("telescoped") deposit of two contrasting types of mineralization: an older volcanogenic massive sulphide (VMS) deposit; and a younger porphyry stockwork. The massive sulphide bodies are composed principally of pyrite and chalcopyrite with minor amounts of sphalerite, galena, tetrahedrite and barite. There are five known large massive sulphide bodies, with plan areas of 8,000m^2 to 26,000m^2, and several smaller ones. These bodies are distributed within the deposit over a strike length of about 600m and over a vertical interval of up to 200m. Past production from these lenses during the Siemens period is reported to have totaled 1.7Mt of ore, with 56,000t of copper and 134t of Au-Ag-Cu doré recovered.

2.3 Mineralogy and Gold Deportment

The sulphide mineralogy of the Gedabek deposit is dominated by pyrite, with lesser chalcopyrite and minor amounts of sphalerite, covellite, chalcocite, galena and arsenopyrite. The py/cpy ratio is generally in the 12-15 range. The gangue mineralogy is dominated by quartz (approx. 50%), with lesser feldspars, muscovite, and andalusite. Minor barite and iron hydroxyoxides are also present.

Gold is found in two main forms: (i) gold minerals, including native gold, electrum and petzite [Ag_3AuTe_2]; (ii) submicroscopic gold in sulphides and goethite. The highest concentrations of sub-microscopic gold occur in arsenopyrite (40ppm Au) and covellite (9ppm Au), but because of its dominance, pyrite is the principal sulphide carrier of sub-microscopic gold. Silver occurs as native silver, electrum, acanthite [Ag_2S], hessite [Ag_2Te] and petzite, of which hessite is the most common, followed by native silver. Silver is also likely to occur in solid solution in covellite. Five telluride minerals are present, of which Bi-tellurides, hessite and altaite [PbTe] are the most common. The so-called oxide ore is characterized by minerals typical of the hypogene oxidation zone of copper porphyry deposits, including malachite, azurite, goethite and other iron hydroxyoxides

3. MINE DEVELOPMENT

3.1 Gedabek Open Pit

The Gedabek open pit was the first modern mine in the Gedabek area. Mine development of a resource of over one million ounces of gold was started in 2009 and the first gold doré was poured in September of that year. The mine has been in continuous production since then, yielding approximately 50 to 70 thousand ounces of gold per year. Currently, the open pit is approaching the end of its economic life, with perhaps another two or three years of operation still ahead.

3.2 Gadir Underground Mine

In 2014, a satellite deposit was discovered about 1km from the open pit. A decline was driven and in June 2015 the new Gadir underground mine began production.

3.3 Ugur Open Pit

Another satellite gold deposit, this time at surface, was discovered in October 2016. The discovery, which was named Ugur, was approximately three kilometers from the main processing facilities at Gedabek. Development of this deposit was fast-tracked with a JORC resource estimate of 199 thousand ounces of gold announced in August, 2017 and production started in October, 2017, just 12 months after the discovery.

3.4 Gedabek Underground Mine

The main Gedabek ore body dips down under a mountain, causing the amount of overburden removal at each push-back of the main pit to increase. By 2020, underground extraction of the dipping ore body had become economically attractive and so a portal was created on the far side of the mountain and a decline driven under the mountain to meet the ore body below the open pit mine. Production from the new decline started in late 2020 and the tunnelling was extended to connect with the Gadir underground mine tunnelling to provide the required number of egresses for safe mining.

4. ORE PROCESSING AT GEDABEK

4.1 Heap Leaching (HL)

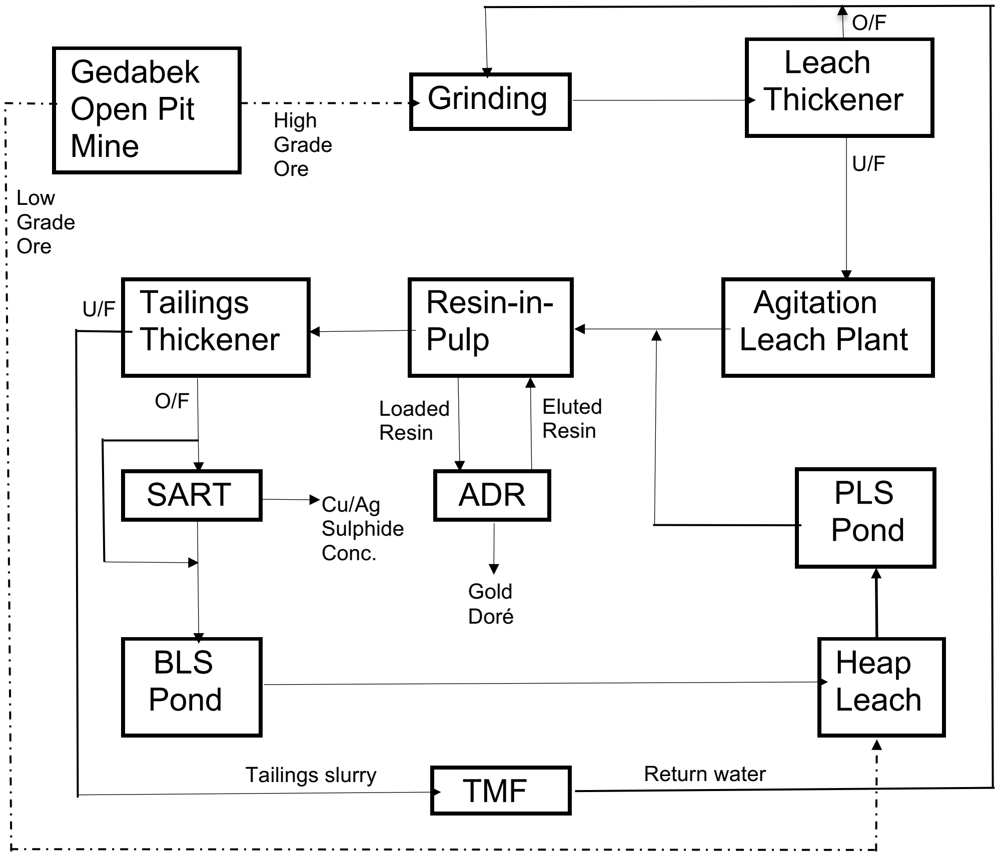
When the Gedabek mine started up in 2009, the ore, which initially was mainly oxidic in nature, was treated by cyanide heap leaching to produce pregnant leach liquor, from which gold was extracted by fixed-bed ion exchange. Resin ion exchange was used at Gedabek, instead of conventional activated carbon, because of the elevated copper concentrations in the leach liquors from the heaps, which typically contained about 1000 ppm Cu. In spite of the high Cu/Au ratios in the Gedabek leach liquors, which usually ranged from 500 to 1000, the excellent selectivity of the Minix resin used in the process was such that the Cu/Au ratio on the loaded resin was about one. In order to prevent copper from building up in the recirculating leach liquors, a SART plant (Sulphidisation-Acidification-Recycling-Thickening) was incorporated in the circuit to remove copper from solution as a copper-silver sulphide concentrate. A description of the operations at Gedabek in the early years of the mine, prior to the introduction of the agitation leach plant, was given in a paper by Hedjazi & Monhemius (2014).

4.2 Agitation Leaching (AGL)

As mining progressed, the ore became less oxidised and harder in texture, with the result that gold recoveries in the heaps started to decrease. In 2012, it was decided that agitation leaching should be introduced to operate in parallel with heap leaching, with high grade ore (>1.5 g/t Au) going to agitation leaching and low grade ore (<1.5 g/t Au) going to heap leaching. Accordingly, a 100 t/h stand-alone agitation leach plant, including resin-in-pulp solution processing, was designed, built, and commissioned by July 2013. The way in which the agitation leach plant was integrated into the original heap leach operation is illustrated by the flowsheet shown in Figure 1.

Following the introduction of the agitation leach plant, soluble copper became a much more important issue at Gedabek. Grinding the ore to minus 75 μm for agitation leaching, instead of crushing it to minus 25 mm for heap leaching, exposed much more of the copper minerals to direct contact with the cyanide leach solutions, which increased the rate and

Figure 1 Gedabek process flowsheet



extent of dissolution of copper. Furthermore, as the mine went deeper, the copper grades of the ore tended to increase. The result of these factors was that the consumption of cyanide and hence the overall operating costs for producing gold became unacceptably high, so that steps had to be taken to modify the process to bring down the costs. To do this, a little-used technique that had been invented at the beginning of the 20th century, in the early years of cyanide leaching, was adopted. The technique involved the addition of ammonia into the cyanide leaching system to suppress the dissolution of copper, without adversely affecting the extraction of gold. A full description of the agitation leach plant at Gedabek, together with a discussion of the effects of adding ammonia into the cyanide leach, was published in 2018 (Hedjazi & Monhemius, 2018). After about one year of operation, ammonia additions at Gedabek were discontinued because the amount of soluble copper in the leach solutions had decreased naturally, due to changes in the ore mineralogy, which comprised more chalcopyrite and less cyanide-soluble secondary copper sulphide minerals.

4.3 Flotation (FLT)

The next development at Gedabek was the introduction in 2015 of a flotation plant to treat the tailings from the agitation leach plant to recover the copper sulphide minerals into a copper concentrate, together with some of the undissolved gold in the tailings. This additional process step increased the overall recoveries of both copper and gold. The plant was run in this configuration until the end of 2016 when, for operational reasons, it was decided to treat the stockpile of sulphide-rich ore that had been accumulated over several years. This change of feedstock necessitated a reconfiguration of the plant so that ore was first treated by flotation to produce a copper-gold flotation concentrate and then the flotation tailings were processed through the agitation leach plant to recover the gold remaining in the tailings by cyanide leaching. A paper comparing the performances of the plant in these two configurations was published in 2017 (Monhemius, Hedjazi & Saeedi, 2017).

4.4 Current Flowsheet

In 2018, a second crushing and grinding circuit was installed, which enabled raw ore to be fed directly to the flotation plant, thus making flotation independent of the agitation leaching plant. The current set-up of the leaching operations at Gedabek closely resembles the pre-2015 configuration shown in Figure 1, but with the addition of an independent flotation plant operating in parallel. Furthermore, heap leaching has also undergone modification over the years. As well as using crushed ore (-25mm) as feed to the heaps, low-grade, run-of-mine (ROM) ore is also leached on separate heaps, without any prior size reduction. Thus in the current processing set-up at Gedabek, ore coming from the mine(s) has to be directed to one of five possible destinations, namely: (i) agitation leaching (AGL); (ii) flotation (FLT); (iii) crushed ore heap leaching (HLC); (iv) run-of-mine heap leaching (HLROM); or (v) stockpile (SPF). These various process routes result in three marketable products: (i) gold doré; (ii) copper flotation concentrate with significant gold credits; and (iii) precipitated copper sulphide with silver credits from the SART plant. The metal recoveries achieved in these processes are shown in Table 1.

Table 1. Metal recoveries in extraction processes

Processes	Recovery %		
	Au	Cu	Ag
AGL	80	30	65
HLC	60	30	5
HLROM	40	20	5
FLT	60	80	70

The decision on which of these processing routes is optimal for any particular batch of ore is based on geometallurgical factors, such as gold grade, copper grade, cyanide leaching amenability and consumption, and ore mineralogy. The geometallurgical system used at Gedabek is outlined in a paper published in 2019 (Aliyev et al., 2019).

5. ORE SORTING

By 2020, the main Gedabek Open Pit mine was quite mature and the gold grades in the remaining ore reserves were starting to decline. With a view to extending the life of the mine by pre-concentrating sub-grade ore, some preliminary test-work was commissioned to examine the feasibility of ore sorting for pre-concentration. 50kg samples of various Gedabek ore types were sent to Steinert in Germany for testing in a pilot-scale ore sorting machine, equipped with x-ray detection technology. The tests were deemed successful and an order was placed for an industrial scale, nominal 100 T/h, Steinert ore sorting machine, equipped with two detectors - a laser module and a XRT module (Model number: KSS 200 520 MS XT 12U M. Ore feed size: min. 10 mm; max. 50 mm. Belt width: 1950 mm. Capacity 60-100 T/h).

The ore sorter was received and commissioned at Gedabek in H2 2021 and a series of large-scale test campaigns using various ore types were undertaken to establish how it could be most effectively incorporated into the ore processing facilities at Gedabek.

5.1 Initial test work

Initial tests with the industrial ore sorter were carried out on 10 ton batches of sub-grade ore from the Gedabek underground mine. Various operational parameters were investigated, principally: (i) feed particle size (range: +12mm to -45mm); and (ii) eject proportion (range: 15 – 30%). The test campaign involved seven tests, totalling 70 tons of ore. The average ore feed grades were 0.5 g/T Au and 0.16 wt% Cu. Eject rates were either 15% or 30%. The average product (eject) grades were 0.77 g/T Au and 0.27 wt% Cu, representing upgrades of 65% and 88%, respectively. Metal recoveries in the ejects were in the range 33-43%.

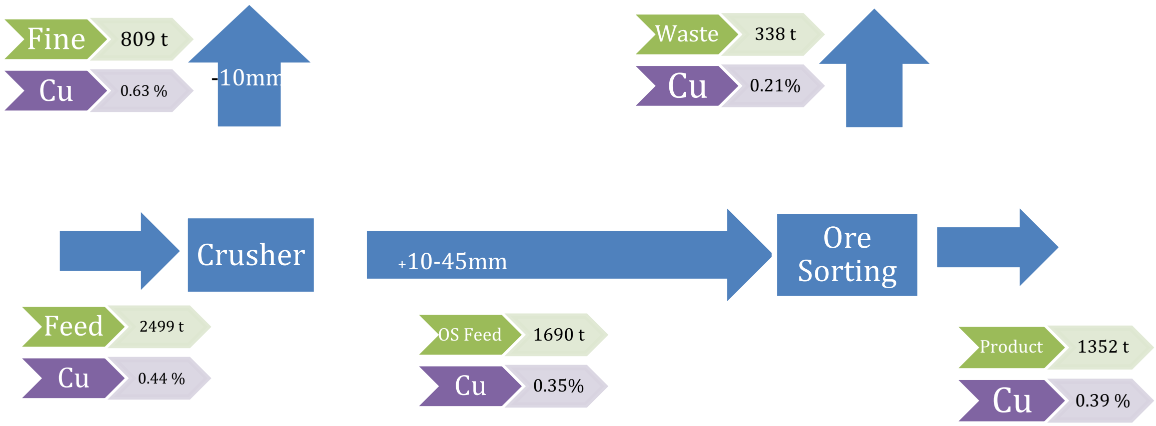
5.2 Larger-scale tests

A second campaign of five larger-scale tests was carried out using low grade ore from the Gadir underground mine. Each test involved a batch of 400 to 500 tons of ore and a total of 2100 tons of ore were used in the tests. The ore was crushed and sized to +10-45mm and the eject rate was set at 30%. The average ore feed grades were 0.80 g/T Au and 0.11 wt% Cu. The average eject grades were 1.08 g/T Au and 0.14% wt% Cu, giving upgrades of 35% and 45%, respectively, with metal recoveries in the ejects of 30 to 45%.

5.3 Extended trial with flotation feed ore

An extended trial of the ore sorter, using 2500 tons of stockpiled flotation feed ore, originating from the Gedabek open pit mine, was then carried out. The ore was crushed to -45 mm and the -10 mm fraction was screened out to give a feed size of +10-45 mm (68% of total ore) for the ore sorting machine. The ore sorter was programmed to discriminate ore particles on the basis of their x-ray density, so that particles with lower densities would be ejected and the ejected ore fraction was adjusted to 20% of the feed to the ore sorter (14% of the total ore). The feed ore copper grade was 0.35 wt%, the ejected ore copper grade was 0.21 wt% and the product from the sorter was 0.39 wt% Cu. The full trial results on 2500 tons of flotation ore from the Gedabek open pit are shown diagrammatically in Figure 2.

Figure 2 Test campaign results on 2500T batch of flotation feed ore.



Crusher Feed	Cu	Ag	Au
t	%	g/t	g/t
2499 (100%)	0.44	4.241	0.451
Feed to OS	Cu	Ag	Au
t	%	g/t	g/t
1690 (68%)	0.354	4.986	0.278
Fine material	Cu	Ag	Au
t	%	g/t	g/t
809 (32%)	0.632	4.027	0.637

OS Feed	Cu
t	%
1690 (68%)	0.354
OS Product	Cu
t	%
1352 (54%)	0.39
OS Eject	Cu
t	%
338 (14%)	0.21

6. DISCUSSION

The test work carried out with low grade ores from the underground mines at Gedabek, described in sections 5.1 and 5.2, showed that pre-concentration by ore sorting provided little or no advantage in the processing of these ore types. Normally, these low-grade, sulphidic ores are treated by run-of-mine heap leaching (HLROM). The increase in grade achieved by ore sorting was not sufficient to enable the upgraded eject portion to significantly better the cut-off grades for enhanced processing, which are set at 1g/T Au for crushed ore heap leaching (HLC), or 0.3 wt% Cu for flotation (FLT). As reported above, the average grades achieved by ore sorting for Gedabek and Gadir underground ores were, respectively, 0.77 and 1.08 g/T for gold, and 0.16 and 0.14 wt% for copper.

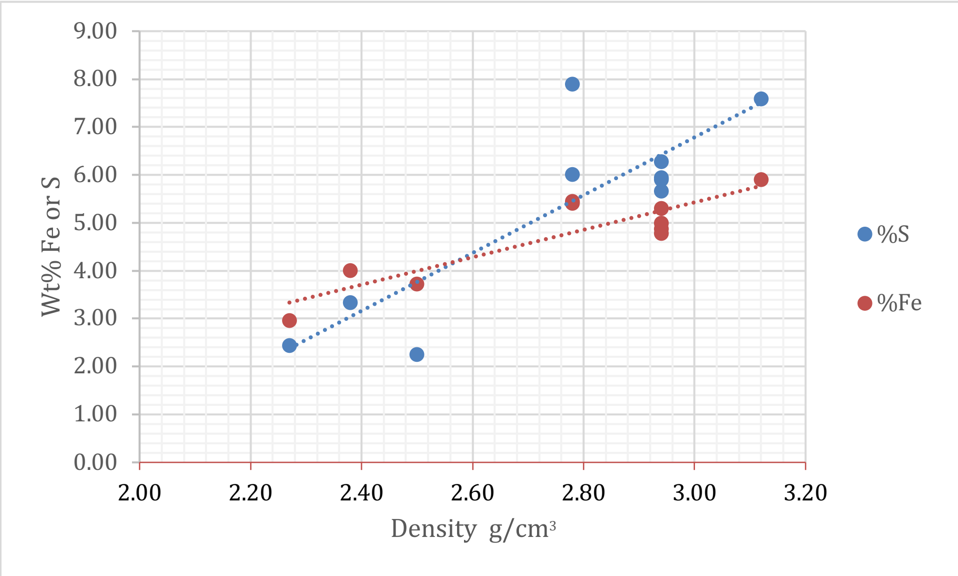
However, the situation was different when copper-rich ore from the Gedabek open pit mine, destined for concentration by flotation, was first put through the ore sorter. The full results are shown in Figure 2. After crushing to -45mm and removal of the fine material (-10mm fraction), the feed to the ore sorter graded 0.35 wt% Cu. After sorting with ejection of the less x-ray dense material, which was 20% by weight of the feed and graded 0.21 wt% Cu, the ore sorter product graded 0.39 wt% Cu, as shown in Table 2. Although the increase in copper grade was modest (11%), the crucial difference was that ore sorting had removed a significant fraction of the copper oxide minerals in the feed. These copper oxide minerals respond poorly to flotation and generally report to the flotation tailings, leading to loss of revenue. The ore sorter eject, which is 14 wt% of the original feed, would be recycled to heap leaching for recovery of the contained gold and a portion of the copper, while the product would join the -10mm fraction to go forward to grinding, prior to concentration by flotation. The feed to grinding was thus 86% of the weight of the original feed and it contained 93% of the original copper.

Table 2. Chemical analyses and measured densities of ore sorter eject and product for flotation feed ore from Gedabek open pit mine.

	Proportion	Density	Cu	Zn	Fe	S	Si
	Wt %	g/cm^3	Wt %	Wt %	Wt %	Wt %	Wt %
Eject	20	2.61	0.21	0.92	4.07	3.92	51.9
Product	80	2.91	0.39	2.40	5.41	6.74	47.1

Mineralogical examination of the eject and product revealed that the density difference between the two streams was primarily determined by the amount of pyrite present. Figure 3 shows the correlations between density and the concentrations of iron and sulphur in samples of the eject and product from the ore sorter. There are two groups of results in the figure – the lower density group is from eject samples and the higher density group is from product samples. Clearly, the product samples contain higher amounts of pyrite than the ejects and, furthermore, there are good linear correlations between density and iron content ($R^2 = 0.79$) and density and sulphur content ($R^2 = 0.73$), showing that pyrite is a primary determinant of the densities of the samples.

Figure 3. Correlations between the densities of ore sorter ejects and products and their Fe and S contents



7. CONCLUSIONS

The test results at industrial scale showed that the best economically viable performance of ore sorting at Gedabek is for pre-concentration of flotation feed ore from the open pit mine and that the ore sorter performance depends primarily on density differences between the mineral-containing and barren rock particles.

The advantage gained by introducing ore sorting ahead of flotation for Gedabek open pit ore is two-fold: (i) the weight of ore fed to grinding is reduced by 14%, thus increasing the throughput of the flotation plant by the same amount; and (ii) the loss of copper to the flotation tailings is decreased, due to removal of non-floatable oxide copper minerals in the ore sorter eject, prior to flotation.

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Glossary

ADR	Adsorption/Desorption/Recovery plant: where gold is eluted from the loaded resin and the stripped resin is returned to RIP, while the strip solution is electrowon to produce gold doré.
AGL	Agitation Leach plant.
BLS	Barren Leach Solution: recycled process solution used as feed to heap leaching.
FLT	Flotation.
HLC	Heap leaching of crushed ore.
HLROM	Heap leaching of run-of-mine ore
PLS	Pregnant Leach Solution: gold-bearing solution from heap leaching.
RIP	Resin-In-Pulp plant: where gold is extracted from the agitation leach pulp and the PLS.
SART	Sulphidisation/Acidification/Recycling/Thickening plant: where Cu and Ag are precipitated from the cyanide leach liquor to produce a mixed Cu/Ag sulphide concentrate.
SPF	Ore stockpile
TMF	Tailings Management Facility.