FLOTATION AND LEACHING AT ANGLO ASIAN MINING'S GEDABEK GOLD AND COPPER MINE IN AZERBAIJAN

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ABSTRACT

Anglo Asian Mining's Gedabek mine is situated in the Lesser Caucasus mountains in Western Azerbaijan. The ore body is a complex copper-gold porphyry deposit, comprising intermixed oxidized, transition and sulphidic gold and copper-bearing ores. Gold in the sulphide ores is generally not refractory and is recoverable by cyanide leaching, but the secondary copper minerals, which are also cyanide soluble, lead to high cyanide consumptions. Ore processing at Gedabek is by agitation leaching for high grade ore (>1g Au/t) and heap leaching for lower grade ore. In order to cope with the high copper concentrations in the cyanide leach liquors, a unique combination of resin-in-pulp for selective gold extraction and SART processing for copper removal and cyanide recovery is used. In 2015, a flotation plant was added to treat the tailings from the agitation leach plant before the tails are sent to the tailings dam. This plant produces a copper sulphide flotation concentrate and also recovers some of the residual gold and silver in the tailings.
Since February 2017, due to lower grades of gold and higher copper in the feed ore, the decision was taken to alter the flow sheet and to carry out flotation ahead of agitation leaching, to reduce the cyanide consumption during leaching by removing soluble copper minerals. The paper compares and contrasts the performance of the plant in the two configurations, namely, (i) leaching followed by flotation and (ii) flotation followed by leaching.

KEYWORDS

Agitation leaching, Copper-gold ore processing, Cyanide consumption, Flotation, Resin-in-pulp, SART process.

INTRODUCTION

In May 2009, Anglo Asian Mining started open pit mining for gold on its Gedabek property in the Lesser Caucasus mountains in western Azerbaijan. Gedabek is situated on the highly mineralized Tethyan Belt that runs from the Himalayas to the Balkans. The ore body at Gedabek is a complex copper-gold porphyry deposit, comprising intermixed oxidized, transition and sulphidic gold-bearing ores. The sulphidic ores contain mainly pyrite and chalcopyrite, with some secondary copper sulphide minerals, such as bornite and chalcocite, and minor amounts of sphalerite, galena and tetrahedrite. Gold in the sulphide ores is generally not refractory and is recoverable by cyanide leaching, but the secondary copper minerals, which are also cyanide soluble, lead to high cyanide consumptions and passivation of free gold.

Ore from the Gedabek mine, which initially was mainly oxidic in nature, was treated by cyanide heap leaching to produce a pregnant leach liquor, from which gold was extracted by fixed-bed resin 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, prior to the introduction of the agitation leach plant, was given in a paper by Hedjazi & Monhemius (2014).

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.

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 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 was invented at the beginning of the 20^{th} 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 recently published (Hedjazi & Monhemius, 2016).

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.

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 in order that the ore was treated first 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. This paper compares and contrasts the performance of the plant in its two configurations, namely: (i) leaching followed by flotation; and (ii) flotation followed by leaching.

PROCESS DESCRIPTION

Agitation leaching

The flow sheet of the agitation leach plant at Gedabek is shown in Figure 1. The design is conventional, except for the resin-in-pulp section, which as far as is known, is unique for this type of application. The account that follows includes modifications made to the plant since the description published previously (Hedjazi & Monhemius, 2016).

Comminution

Mined ore from the stockpile is fed into a silo by a front-end loader. The broken ore is moved from the silo by an apron feeder over a vibrating grizzly, with the oversize passing through a single jaw crusher (1100 x 900 mm). Undersize and crushed ore at minus 15 cm size is conveyed to one of the two SAG mill/ball mill combinations. The SAG mill (5000 x 2800 mm, 750 KW) reduces the ore to minus 1mm. The SAG mill discharge is cycloned, with a cut 80% less than 75 µm, the underflow passing to a ball mill (4000 x 6000 mm, 1.4 MW), with the cyclone overflow joining the ball mill discharge. The combined ball mill discharge is then cycloned again, with 80% less than 75 µm. The overflow from these cyclones is the main feed to the leach tanks, which is first thickened to 40 wt% solids in the grinding thickener, before passing into the first leach tank. The underflow from these cyclones goes to a continuous Knelson concentrator (CVD64) to remove any particles of free gold. The Knelson concentrate is leached in a separate tank with a strong cyanide solution (>2000 ppm CN) for sufficient time to fully dissolve all the free gold.

Leaching

Underflow from the grinding thickener (40wt% solids) is pumped to the first leach tank at a rate of 160 m^3/h. There are seven leach tanks in series; each tank is 11.5 m in diameter and 12 m in height, with a working capacity of 1100 m^3. The tanks are constructed from mild steel and each tank is agitated by a double stage 4-blade propeller, diameter 3.8 m, driven by a 55 kW electric motor. The residence time of the pulp in the leaching train is 48 hr. Cyanide and milk of lime for pH control are added in Tank 1 and further additions of cyanide are made in Tanks 3, 5 and 7. Air is blown into all tanks.

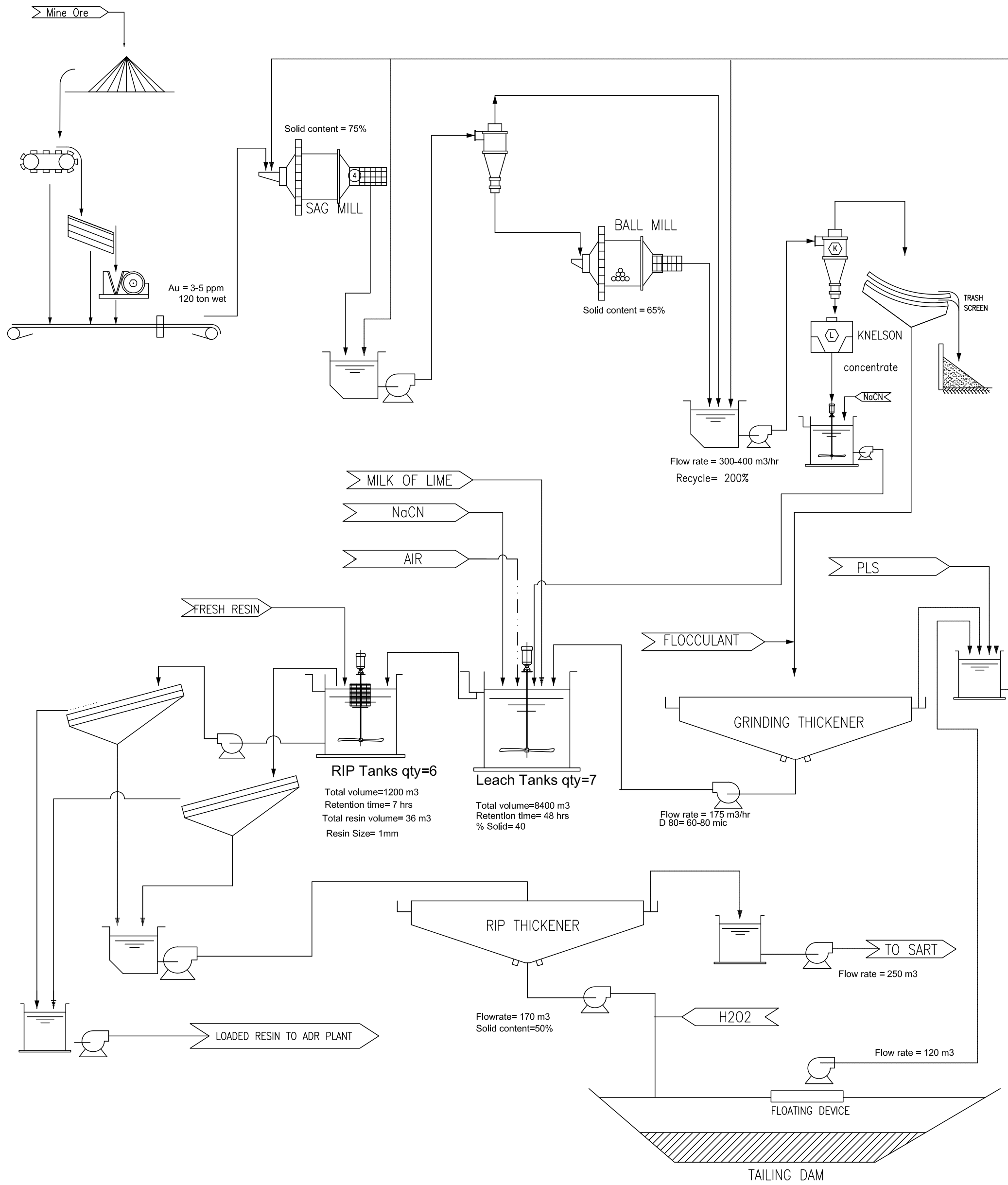

Figure 1. Flow sheet of the Agitation Leaching Plant

Resin-in Pulp (RIP)

Leached pulp from leach tank 7 flows directly to the first tank in the resin-in-pulp section, together with the PLS solution from the heap leach operations. There are six tanks in this section, each of $150m^3$ working capacity, 5.5m in diameter by 8.5m in height, and each is equipped with a Kemix AAC Pumpcell contactor, MSP(P) type. Each contactor holds 6 m^3 of resin (DOWEX XZ-91419, particle size 760 – 1200 µm). The RIP tanks are operated in series in a carousel-fashion: fresh leach pulp enters the first RIP tank and barren pulp exits from the sixth tank, after a total residence time of two to two-and-a-half hours. When the resin in the first tank is fully loaded, that tank is taken off-line by directing the fresh leach pulp to the second tank in the series, it consequently becoming the number one tank, of five then on-line.

The loaded resin in the off-line tank is discharged and pumped to the elution column for stripping and subsequent gold bullion production and then the tank is recharged with freshly-eluted resin. This procedure takes about four hours and when completed, the recharged tank is brought back on-line in position number six in the carousel. As soon as the resin in the new number one tank is fully loaded, this procedure is repeated, and so on, so that at any given time, either five or six RIP tanks are on-line. Barren pulp from the last tank in the series flows into the tailings thickener, where it is thickened to 50-52% solids, with the underflow being pumped to the tailings dam, while the overflow goes to the SART plant for recovery of copper and silver.

Flotation plant

In late 2015, a flotation plant was introduced to treat the tailings from the RIP section to recover a copper sulphide concentrate, together with some of the unleached gold in the tailings. The flotation section comprises six rougher-scavenger cells ($50m^3$), eight cleaner cells ($5m^3$) and four re-cleaner cells ($5m^3$). The pH is adjusted to the desired pH with sulfuric acid or milk of lime as necessary and SIBX/PBX collectors and MIBK frother are added in a conditioning tank. The pH is adjusted to optimize the copper recovery and minimize zinc in the copper concentrate. To depress zinc, zinc sulfate solution is added to the conditioning tank.

After more than a year of operation in this mode, it was decided that for various reasons, but principally because of increasing Cu/Au ratios in the ore feed, the process would be reconfigured so that flotation was carried out ahead of leaching. This arrangement meant that copper minerals from the ore would be removed into a flotation concentrate before leaching, with the expectation that lower copper in the leach feed would reduce the consumption of cyanide during leaching.

<u>Leaching followed by flotation (L+F)</u>

The solution flow sheet of the integrated plant is shown in Figure 2. Return water is pumped from the tailings dam to the process water holding tank, where it joins the overflow from the grinding thickener. Water from this tank is pumped to the grinding circuit where it is mixed with fresh ore by adding it to the SAG mill and ball mill feeds. After agitation leaching and gold extraction by RIP, the leached tailings ($250m^3/h$) pass to the flotation plant, where a copper concentrate is produced. After flotation, water is recovered from the barren tailings in the tailings thickener, with the underflow being pumped to the tailings dam. Part of the overflow from this thickener ($140m^3/h$) is passed through the SART plant, where dissolved copper and silver are recovered as a precipitated copper-silver sulphide concentrate. Water leaving the SART plant rejoins the remainder of the tailings thickener overflow and flows to the barren leach solution pond (BLS). Water from this pond is used as the feed to heap leaching. Pregnant solution from the heaps is collected in the pregnant leach solution pond (PLS), from where it is pumped back to enter the agitation leach system just ahead of the RIP tanks, so that both heap-leached and agitation-leached gold is recovered by the RIP system.

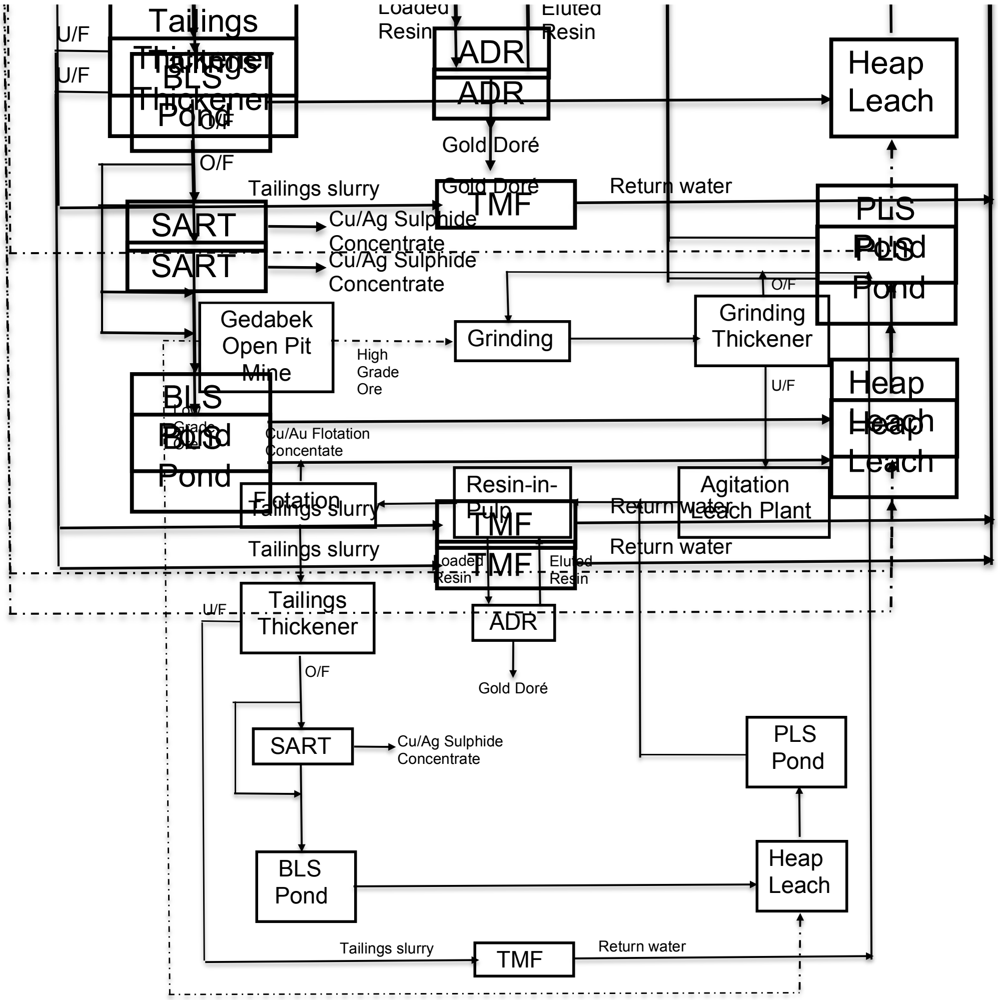

Figure 2. Flow sheet of the integrated process at Gedabek with leaching followed by flotation (L+F).

<u>Flotation followed by leaching (F+L)</u>

As stated above, it was decided that for operational reasons, the stockpile of sulphide ore that had been accumulated over several years of mining would be processed through the agitation leaching plant from the start of February 2017. Due to the metal grades in the stockpiled ore and the prevailing metal prices, it was decided to reconfigure the plant so that flotation was carried out ahead of leaching. By removing copper minerals from the ore into a flotation concentrate before leaching, it was anticipated that the consumption of cyanide during leaching could be kept to acceptable levels, in spite of the relatively high copper/gold ratio of the incoming ore. Thus the pipework in the plant was altered so that the freshly ground ore in the underflow from the grinding thickener passed directly into the flotation plant. This stage produced a copper-gold flotation concentrate, while the flotation tailings flowed on into the agitation leach plant for the recovery of the remaining gold and soluble copper by cyanide leaching. The remainder of the overall process was unaltered. The reconfigured flow sheet is shown in Figure 3.

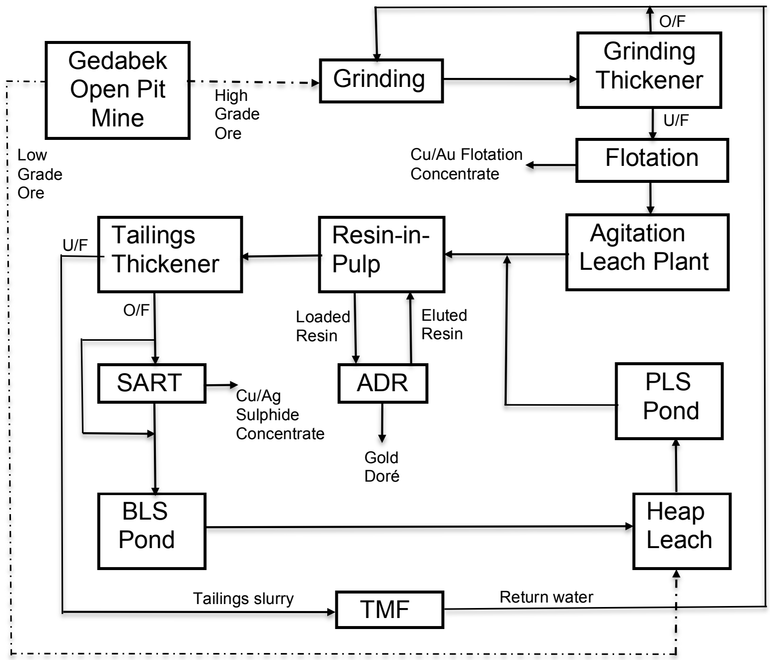

Figure 3. Flow sheet of the integrated process at Gedabek with flotation followed by leaching (F+L).

RESULTS AND DISCUSSION

Operational data from the Gedabek process plant during January 2017, the last full month of operation in the (L+F) configuration, is shown in Table 1. It can be seen that the average gold recovery in the leaching plant was 57.5%, with an overall cyanide consumption of 4.54 kg of NaCN per ton of ore leached. In the flotation plant, a further 40.8% of the gold remaining in the leached tailings was recovered into the flotation concentrate, resulting in an overall gold recovery of 74.9%. In the case of copper, 24.0% was dissolved during leaching, which accounts for the relatively high cyanide consumption, with a further 39.0% of the unleached copper in the leach tailings being recovered into the flotation concentrate, giving an overall copper recovery of 53.7%. Silver behaved differently, with none dissolving during leaching and 33.3% going in to the flotation concentrate, giving an overall silver recovery of 33.3%. The dissolved copper, together with part of the associated cyanide, was recovered in the SART plant, which produced a precipitated Cu/Ag sulphide concentrate with the composition given in Table 3, while the recovered cyanide was recycled within the process. The silver reporting to the SART concentrate arises from the heap leach solution (PLS), which does contain dissolved silver and which is mixed with the agitated leach pulp ahead of the RIP plant, as shown in Figures 2 and 3. The average composition of the flotation concentrate during January is also shown in Table 3.

The results from the first month of operation of the reconfigured plant (February 2017), where the ore is subjected first to flotation, with the flotation tailings being leached, are shown in Table 2. It can be seen that this change of configuration resulted in 49.0% of the gold in the feed reporting to the flotation concentrate, with a further 56.2% of the gold remaining in the flotation tailings being recovered in the agitation leaching plant, giving an overall gold recovery of 77.6%. In the case of silver, 37.6% was recovered into the flotation concentrate, while no silver was dissolved in the agitation leach. Copper had the highest recovery into the flotation concentrate at 62.0%, with a further 31.6% of the remaining copper dissolving during leaching, giving an overall copper recovery of 74.0%. As anticipated, the lower copper content of the flotation tailings lead to a lower consumption of cyanide during leaching, which was 3.74 kg NaCN/ton ore, a saving of 18% over the previous (L+F) configuration.

Table 1. Results and recoveries for leaching followed by flotation

Leaching plus Flotation (L+F)			
Ore Feed Rate	2153 ton/day		
Cyanide Consumption	4.54 kg/ton		
Grades	**Au (ppm)**	**Ag (ppm)**	**Cu (wt%)**
Ore feed	1.67	16.5	0.54
Leach tails	0.71	16.5	0.41
Flotation tails	0.42	11.0	0.25
Recoveries	**Au (%)**	**Ag (%)**	**Cu (%)**
Agitation Leaching	57.5	0.0	24.0
Flotation	40.8	33.3	39.0
Overall	74.9	33.3	53.7

Comparison of the overall metal recoveries shown in Tables 1 and 2, shows that recoveries by the (F+L) route are higher in all cases, with 3% more gold, 4% more silver and 20% more copper. The much higher recovery of copper into the flotation concentrate is due mainly to the greater amenability of freshly ground copper mineral surfaces to flotation, compared with those exposed first to cyanide solutions and aeration in the agitation leach tanks.

Table 2. Results and recoveries for flotation followed by leaching

Flotation plus Leaching (F+L)			
Ore Feed Rate	1843 ton/day		
Cyanide Consumption	3.74 kg/ton		
Grades	**Au (ppm)**	**Ag (ppm)**	**Cu (wt%)**
Ore feed	1.43	14.9	0.50
Flotation tails	0.73	9.3	0.19
Leach tails	0.32	9.3	0.13
Recoveries	**Au (%)**	**Ag (%)**	**Cu (%)**
Flotation	49.0	37.6	62.0
Agitation Leaching	56.2	0.0	31.6
Overall	77.6	37.6	74.0

The compositions of the flotation concentrate and the SART concentrate produced from the reconfigured (F+L) plant are shown in Table 3, where it can be seen that the (F+L) configuration produces flotation concentrate at a greater rate than the (L+F) route, about 55% more by weight. In the case of the SART concentrates produced by the two routes, it can be seen from Table 3 that the compositions of the concentrates are similar, but there is less concentrate produced by the (F+L) route (approximately 17% less), because there is less copper dissolved in the leach step and hence less copper sulphide precipitated in the SART process.

Table 3. Production data for SART and Flotation concentrates.

Plant Configuration	Concentrate	Analyses			Production Rate (t/d)
		Cu (wt%)	Au (ppm)	Ag (ppm)	
L + F	SART	52.3	0.4	423.0	5.3
	Flotation	18.5	20.4	630.0	17.4
F + L	SART	48.0	0.4	338.0	4.4
	Flotation	16.1	27.3	370.0	27.0

The integration of the flotation plant into the process flow sheet has been engineered in such a way that flotation can be carried out either before or after agitation leaching. The decision on which scheme should be used is based on the economics of production, which is determined by the following factors:

- Metal grades (Au, Cu) in the ore;
- Metal prices;
- Recovery of each metal in the alternative schemes;
- Production cost of each scheme.

Using the data in the Tables above, together with current metal and cyanide prices (i.e. Au = \$1200/oz, Ag = \$18/oz, Cu = \$6000/ton and NaCN = \$1.80/kg), it can be calculated that the extra revenue created by changing the plant configuration at Gedabek from (L+F) to (F+L), for an ore feed with an analysis similar to that given in Table 1, amounts to about \$20,000/day, or over \$7 million per year.

CONCLUSIONS

Flotation of the Gedabek copper-gold ore ahead of cyanide leaching, compared with leaching before flotation, increases the recovery of copper by about 20% and decreases the consumption of cyanide during leaching by about 18%. There are also small increases in the overall recoveries of gold and silver. The quantity of the flotation concentrate is increased by about 55%; the copper contents of the concentrates are similar in both cases, but the gold content is increased by about one third. The decreased cyanide consumption and increased metal recoveries have a significant effect on the process economics, leading to an increase in annual revenues of several million dollars.

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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.
F	Flotation.
HL	Heap Leach plant.

L	Leaching
MIBK	Methyl iso-butyl ketone frother
PBX	Potassium butyl xanthate collector
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 copper and silver are precipitated from the cyanide leach liquor to produce a mixed Cu/Ag sulphide concentrate.
SIBX	Sodium iso-butyl xanthate collector
TMF	Tailings Management Facility.