The Industrial Application of Ultrafiltration and Reverse Osmosis for the Recovery of Copper, Silver and Cyanide from Gold Leach Liquors

Farhang Hedjazi and A. John Monhemius

Abstract Anglo Asian Mining have recently installed an industrial-scale UF/RO plant to treat process liquors from the integrated heap leach/agitation leach/resin-in-pulp gold ore treatment facilities at their Gedabek gold-copper mine in Azerbaijan. The UF/RO plant is designed to treat 60 m^3/h of leach solution to produce discharge quality water. The RO concentrate, which contains elevated concentrations of copper, silver and cyanide, is sent to the company's SART plant for the recovery of the metal values as a precipitated sulphide concentrate and the cyanide, which is recycled to leaching. The new water treatment plant improves the sustainability of the operations at Gedabek by enabling replacement of fresh water input with RO permeate and safe discharge of permeate to the environment, during periods of excess water balance. The paper includes pilot plant data and early results from the full-scale plant.

Keywords Gold-copper ore treatment • Gedabek mine • Azerbaijan
Ultrafiltration and Reverse Osmosis • Cu and Ag recovery by SART
Cyanide recovery

Introduction

Anglo Asian Mining produces gold and copper from its mines at Gedabek in western Azerbaijan. The ore body at Gedabek, which is situated in the Lesser Caucasus mountains and lies on the well-known Tethyan mineralisation belt, is a complex copper-gold porphyry deposit. Ore from the main Gedabek open pit and its satellite mines is treated by a variety of processes comprising heap leaching, agitation leaching, flotation and SART processing. Gold is produced both as doré and in the

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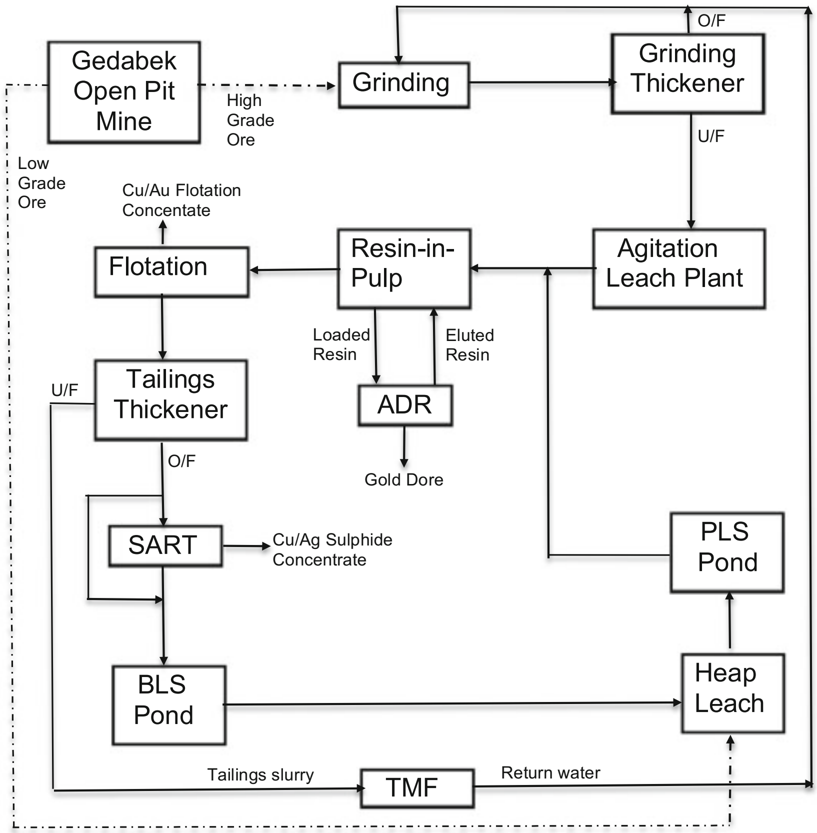

Fig. 1 Flow diagram of the current ore processing facilities at Gedabek. (Explanations of the acronyms can be found in the glossary)

copper flotation concentrate. Copper is also produced, together with silver, in a sulphide concentrate by the SART process. A flow diagram showing the current processing circuit at Gedabek is shown in Fig. 1 and full descriptions of the plant and the various processing options can be found in previously published papers [1–3].

Because of the copper minerals in the Gedabek ore, a considerable amount of copper dissolves in the cyanide leach liquors. As each copper ion in solution is complexed with an average of three cyanide ions [2], the amount of cyanide held in solution as WAD (weak acid dissociable) complex ions is significant and this adversely affects the cost of ore processing. Part of the WAD cyanide is recovered in the SART plant, where copper (plus any dissolved silver) is removed from the leach liquor as a copper sulphide precipitate. The removal of copper releases complexed cyanide into solution and makes it available for gold leaching. The capacity of the SART plant (100 m^3/h) is not sufficient to treat the whole leach liquor flow, with the result that the recirculating process solutions typically contain 0.5–1.0 g/L Cu, together with the associated complexed cyanide, where 1g Cu will complex with about 1.2g CN.

Since the start of mining operations at Gedabek in 2009, ore processing has been operated on a zero discharge basis, with all process solutions being stored on the mine property and mainly in the tailings dam. The climatic conditions at Gedabek are such that in normal years there is a positive water balance, with typically about 300,000 m^3 of water added to the inventory each year. Eventually, storage of this excess water would become unsustainable and so it was decided to install a water treatment system that could treat the process solutions to recover dissolved metals and cyanide and produce water clean enough to replace current fresh water inputs to the process, and also for direct discharge to the environment, when necessary.

Membrane technology was the technique selected to accomplish these objectives. Laboratory scale test work soon demonstrated that reverse osmosis alone, or reverse osmosis in combination with ion exchange, could purify Gedabek process solutions to the required specifications. On completion of the laboratory tests, the decision was made to run pilot plant tests, which were carried out on site at Gedabek, using actual process solutions.

Pilot Plant

The pilot plant consisted of two independent units, the Ultrafiltration (UF) module and the Reverse Osmosis (RO) module. The RO module had a capacity of up to 1000 L/h of feed solution, with feed pressures of up to 30 bar. The process water was first fed to the UF module to remove suspended solids. The UF membrane was backwashed at pre-determined intervals to flush solids from the membrane. Clarified solution from the UF plant was collected in the RO feed buffer tank (1 m^3 isotainer) and fed by gravity to the RO plant feed tank. Anti-scalant was dosed at a pre-determined rate to the RO feed tank. Solution from the RO feed tank was pumped to the RO unit. Permeate was collected in an RO permeate holding tank. A portion of the RO concentrate was recycled back to the RO plant feed tank, whilst a bleed stream was removed depending on the permeate-to-concentrate ratio required. The flow diagram of the pilot plant tests is shown in Fig. 2. The RO pilot plant was run on a continuous basis in campaigns of up to 10 days duration, with various combinations of feed flowrates, pressures and permeate recoveries. Two types of RO membrane were tested, together with two types of anti-scalant.

Process water fed to the pilot plant typically contained about 1000 mg/L Cu, 1 mg/L Ag, 0.25 mg/L Au and 1500 mg/L total CN, of which about 100 mg/L was free CN. The water was saturated with respect to gypsum, with over 2000 mg/L SO_4 and about 600 mg/L Ca in solution, and an important objective of the test work was to find a suitable anti-scalant to prevent blockage of the RO membrane with gypsum.

Results from the most successful combination of membrane (Lewabrane RO BO85 FR 4040) and anti-scalant (Spectraguard, USA) are given in Table 1. In this test, the RO unit was run continuously for over 200 hours, at a feed rate and pressures of 750 L/h and 20 or 30 bar, respectively. The permeate flow varied between 120 and 190 L/h, averaging about 150 L/h. Addition of Spectraguard anti-scalant at a rate of 6 mg/L to the feed water was sufficient to prevent any significant scaling, or loss of performance, of the membrane during the extended test.

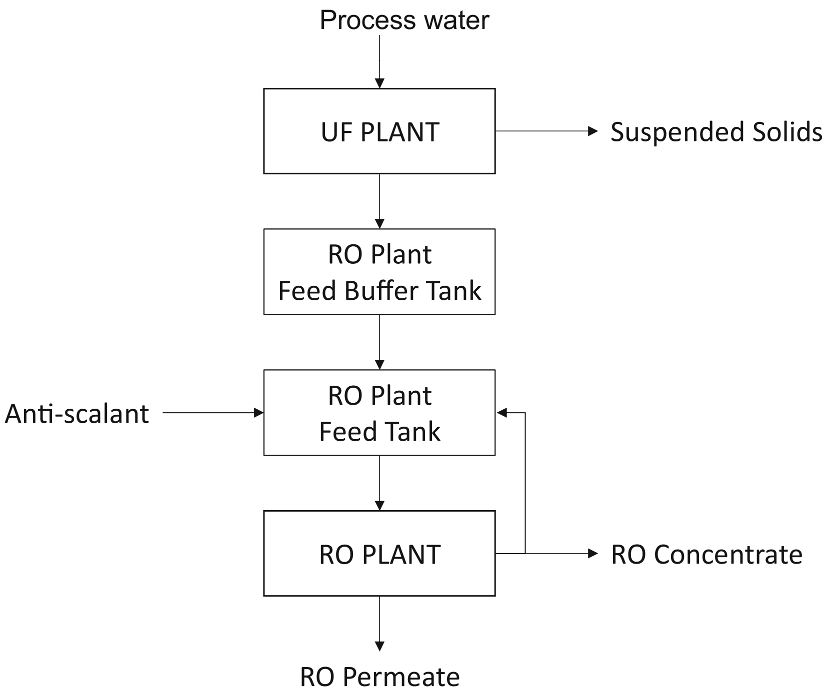

Fig. 2 Flow diagram for the pilot plant tests

Table 1 Results from pilot plant tests

Recovery to permeate%	Operating pressure (bar)	Cu in feed (mg/L)	Cu in permeate (mg/L)	Metal deportment to permeate (%)		
				Cu	Au	Ag
62	30	1045	26	1.4	8.1	2.5
67	30	1023	26	1.1	4.8	2.1
67	30	1024	33	1.4	7.3	3.8
50	20	1052	16	0.9	8.8	1.7
50	20	1057	19	0.8	5.7	5.1
25	30	1016	11	1.1	4.3	1.5
35	30	1011	11	0.8	3.3	2.3

The main conclusions from the extended pilot plant test work were:

- Cu concentration in the feed varied between 1006 and 1081 mg/L, with the average at 1049 mg/L, and between 0.8 and 1.4% of the Cu reported to the permeate, i.e Cu in the permeate varied between 11 and 33 mg/L;
- The gold concentration in the feed varied between 0.22 and 0.24 mg/L, whilst in the permeate it varied between 0.01 and 0.04 mg/L.
- Silver in the feed varied between 0.65 and 0.69 mg/L and on average, less than 3% silver reported to the permeate stream, hence the behavior of silver seems to be similar to that of copper;

- More than 99% of the cyanide, free and total, was removed from the permeate.

The results shown in Table 1 were obtained with a single stage of reverse osmosis. It was further demonstrated that a second pass of the permeate through the RO unit reduced the concentration of copper in the permeate to less than 1 mg/L, with Au and Ag being undetectable.

Industrial Plant

Based on the pilot plant test work, an industrial UF/RO plant was designed to produce 60 m^3/h clean water from Gedabek process solutions. The industrial plant has four stages of treatment, namely: (i) sand filters; (ii) ultra-filters; (iii) first-stage reverse osmosis; and (iv) second-stage reverse osmosis. Each of the treatment units is housed in a standard-sized shipping container. The containers were fitted out with their equipment and instrumentation at the manufacturer's site (Nanoretech Systems (Pty) Ltd) in South Africa. The containers were then shipped to Azerbaijan and placed in position on the Gedabek plant site, where they were connected to power supplies and to a series of pre-built liquid storage tanks, to create a functioning, mainly prefabricated, plant. A simplified flow diagram of the industrial plant is shown in Fig. 3.

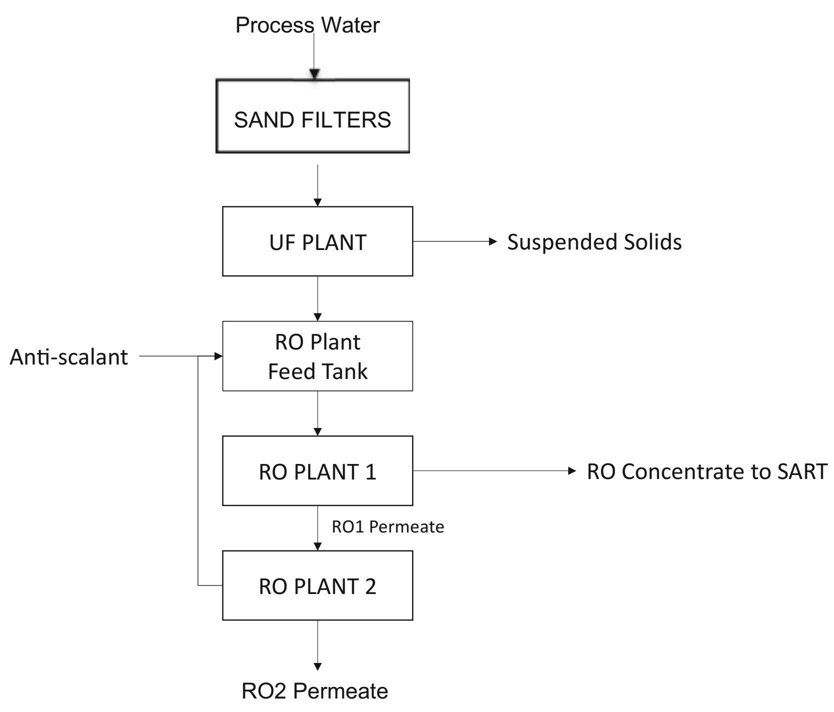

Fig. 3 Simplified flow diagram of the industrial UF/RO plant

Process solution first enters a series of five sand filters. The filters are fed with solution under pressure by a centrifugal pump with a maximum flow of 90 m^3/h at 3 bar pressure. The filtrate passes to the ultrafiltration unit, comprised of 12 Dow SFP 2880 UF modules. These are U-PVC cylinders, filled with PVDF hollow fiber membranes of 0.03 μm nominal pore diameter, for the removal of bacteria, viruses, and particulates, including colloids, to protect the downstream RO units. The UF modules operate with an outside-in flow configuration and are pressurised to 2 bar, typically giving a flowrate of about 6 m^3/h per module. Filtrate from the UF unit passes to the RO feed tank, from where it is pumped into the first of two reverse osmosis units. Anti-scalant is continuously fed into the RO feed tank.

The RO modules are high pressure tubes rated to 1000 psi (69 bar), each tube containing six composite polyamide membrane RO elements (Lewabrane® RO B400). UF filtrate is pumped into the first RO stage (RO1) at a pressure of 20 bar by a variable speed multistage pump capable of delivering up to 90 m^3/h. Recovery to the permeate in the first stage is 70% by volume. The first stage permeate is pumped to the second stage, RO2, while the RO1 concentrate is sent to the SART plant for recovery of Cu, Au, Ag and CN. In RO2, second and third passes are made through low energy membrane units with recoveries of 90% volume at each pass. The permeate from RO2 is the clean water product, while the RO2 concentrate is recycled to join the feed to RO1.

The sand filters and the ultrafiltration units each have automatically controlled back-wash systems, whereas the RO units have both automatic back-wash and chemical conditioning systems to keep the membranes clean and operating efficiently. Pictures of the interiors of the ultrafiltration and reverse osmosis containers at Gedabek are shown in Figs. 4 and 5, respectively.

Fig. 4 Ultrafiltration plant

Fig. 5 Reverse osmosis plant

Results

Commissioning of the RO plant began in November 2017, just as the winter started to set in at Gedabek, which is situated at an altitude of 1600 m and hence can experience severe winter conditions. Commissioning proceeded fairly smoothly, but it rapidly became evident that the reverse osmosis membranes do not function very efficiently at temperatures below about 5 °C, i.e. temperatures that are commonplace at Gedabek during winter, particularly at night. As a result, the plant is currently being operated only during daylight hours during the winter months, typically for a maximum of six hours per day. In due course, heaters will be installed at key points in the plant to enable it to be operated on a continuous basis throughout the year.

The results reported in Table 2 are mean values for the month of January, when the plant was being operated on an intermittant schedule and producing about 200 m^3 of clean water per day. By February, the plant had reached an output of 600 m^3 of clean water per day.

Table 2 Mean results from the industrial UF/RO plant for the month of January

Process Flow	Au (mg/L)	Ag (mg/L)	Cu (mg/L)	Na (mg/L)	Ca (mg/L)	CN[a] (mg/L)
Input	0.09	2.3	449	1578	552	9.2
UF filtrate	0.09	2.3	449	1578	552	9.2
RO1 permeate	0.02	0.09	12.6	39.0	10.7	10.1
RO1 concentrate	0.24	5.2	1296	4403	1635	6.9
RO2 permeate	0.007	0.001	0.79	8.2	4.0	1.26
Final output after detoxification	ND	ND	0.36	8.8	5.0	0.01

[a]The CN is free cyanide in all cases except for Final output which is the sum of Free + WAD cyanide

In Table 2, it can be seen that the input solution to the treatment plant contained approximately 0.5 g/L copper, together with its associated (WAD) cyanide and about 10 mg/L free cyanide, with minor amounts of Au and Ag. The solution was saturated with respect to gypsum and contained over 500 mg/L calcium. The concentrations of dissolved ions were unchanged by ultrafiltration, but after the first stage of RO (RO1), over 97% of the copper had been removed from the permeate, together with 99% of the WAD cyanide. Similar proportions of the other metal ions were removed from the RO1 permeate. The RO1 stage was run with 70% volume recovery to the permeate. The metal concentrations in the RO1 concentrate (30 vol%), which is sent to the SART plant for metal and cyanide recovery, were approximately three times more concentrated than the feed solution, as was the WAD cyanide. After the second stage of RO, the metal and cyanide concentrations were very low and the RO2 permeate was suitable for reuse within the processing plants in place of fresh water inputs. In order to be able to dispose of the RO2 permeate to the environment for water balance purposes, it would be necessary to add a small amount of hydrogen peroxide to destroy the last traces of cyanide in the permeate before discharge (i.e. detoxification).

Conclusions

1. Laboratory and pilot plant tests showed that a combination of ultrafiltration and reverse osmosis can be used to produce clean water from cyanide leach solutions that are saturated with calcium and contain up to at least one gram per litre of copper.
2. An industrial-scale UF/RO plant has been built based on these test results that is designed to produce 60 m^3/h of clean water.
3. The industrial plant has been successfully commissioned and has now been run for several hours per day for a number of weeks.
4. The performance of the industrial plant is as good as, if not better than, the test work results.
5. The anti-scalant has performed as intended and has prevented fouling of the RO membranes, in spite of the high calcium content of the input solutions.

Glossary

ADR Adsorption/Desorption/Regeneration 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

HL Heap Leach plant

PLS Pregnant Leach Solution: gold-bearing solution from heap leaching

RIP Resin-In-Pulp plant: where gold is extracted from the agitated leach pulp and the PLS

RO Reverse Osmosis

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

TMF Tailings Management Facility

UF Ultrafiltration

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