

¹GOLD RECOVERY FROM COPPER-RICH ORES EMPLOYING THE PUROLITE S992 GOLD-SELECTIVE ION EXCHANGE RESIN

J. van Deventer*, M. Kotze**, V Yahorava**

* Purolite International, South Africa **Mintek, South Africa

Presented by

Johanna van Deventer

johanna.vandeventer@purolite.com

ABSTRACT

There has been renewed global interest in the exploitation of historically marginal gold ore bodies, as a result of the recent steep rise in the gold price. The majority of these ores are complex and many of them contain significant amounts of copper minerals. The presence of copper causes a number of problems, including lower gold recoveries, increased cyanide consumption and increased toxicity of the effluent.

A variety of processes have been proposed to recover the copper and/or cyanide, amongst others the SART (Sulphidisation, Acidification, Recycling and Thickening) process. Any process that is performed on the pregnant leach liquor prior to gold recovery could cause gold loss, especially if a high removal efficiency of copper cyanide is required prior to gold recovery.

This paper discusses the use of a commercially available ion exchange resin with an exceptionally high selectivity for gold over copper. This would allow the effective recovery of gold from cyanide leach liquors that contain a relatively high copper concentration, thereby decreasing the risk of gold loss and potentially minimise the adsorbent inventory and flowrate.

¹ Presented at the Alta 2012 Gold Conference, 31 May to 1 June 2012, Perth, Australia

INTRODUCTION

A typical flowsheet^[1,5,8] that incorporates the SART process to recover copper from gold/copper ores after cyanidation, is illustrated in Figure 1 as “Current Flowsheet”. This type of process was developed to allow the economical treatment of ores with a high cyanide-soluble copper content^[3,11]. Copper-containing minerals are problematic, because it forms stable copper-cyanide complexes upon leaching with cyanide. The dissolution of copper consumes a substantial quantity of cyanide, thereby increasing reagent costs. In addition, any copper-cyanide in the pregnant leach liquor competes with gold for capacity on the activated carbon, thus resulting in the carbon to be rapidly exhausted in liquors with high copper concentrations. High copper loadings require additional cost to strip copper separately from gold, and/or reduce the gold electrowinning cell efficiency and result in an undesirably high copper content of the final bullion.

In the SART process, the cyanide associated with copper is released via NaHS precipitation of copper sulphide, which might be a valuable by-product. Cyanide is converted to HCN under the weakly acidic operating conditions (pH 4-5). The Cu₂S is separated from the liquor and the HCN in the overflow liquor converted back to free and recyclable cyanide during subsequent neutralisation. The process allows cyanide to be recycled, thereby reducing reagent costs and allowing the leach circuit to be economically operated at higher cyanide levels, maximising gold leaching efficiency.

In the “Current Flowsheet”, there is a risk of gold loss in the various unit operations upstream of the actual gold recovery step. Strict pH control and sulphide addition is required during the NaHS precipitation step, to prevent loss of gold as gold-sulphide. Any gold precipitate would report to the underflow with the other metal-sulphides, instead of continuing to the gold recovery step. The current flowsheet contains two liquid-solid separation steps after solubilising the gold in the leach and prior to gold recovery, providing two opportunities for the loss of soluble gold.

An alternative flowsheet is suggested, as shown in Figure 1 as “Alternative Flowsheet”. Gold is recovered from the pregnant leach liquor prior to any additional processing steps. This is made possible by the use of a special selective resin, the Purolite S992^[12]. This resin has a relatively low affinity for copper cyanide, thus ensuring high gold loadings are achieved, even from liquors with high copper concentrations. This results in the production of doré bars of a much higher purity, due to limited copper reporting to the electrowinning circuit. This is a medium-base resin, hence stripping of gold is done with dilute caustic solution containing some cyanide.

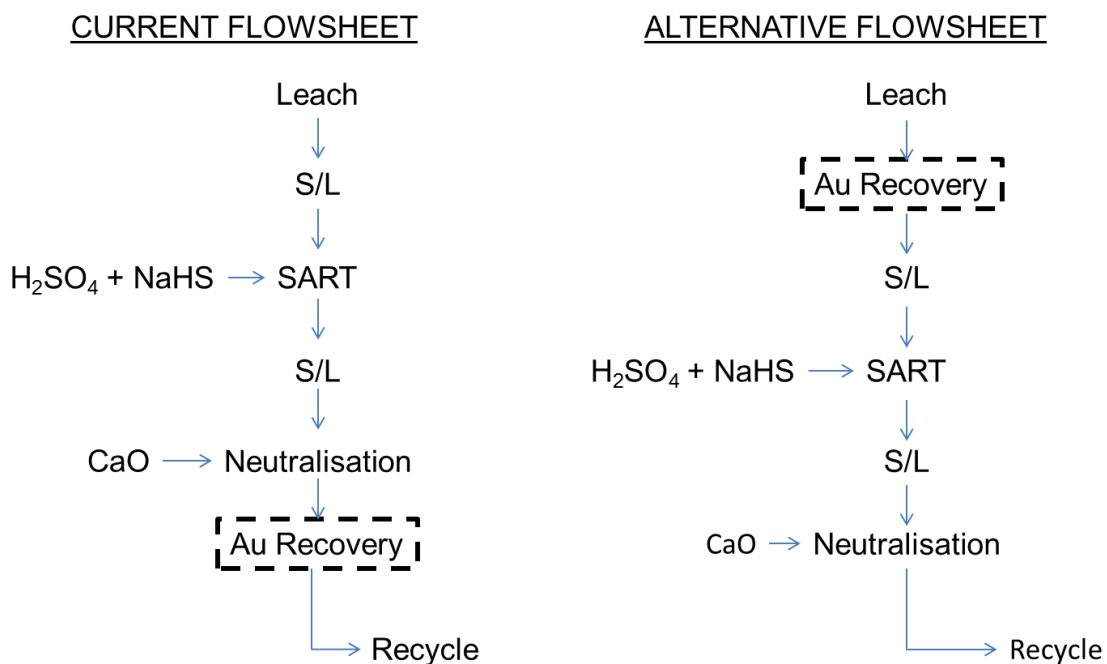


Figure 1 Current and alternative flowsheets for copper and gold recovery from Au/Cu ores

RESULTS AND DISCUSSION

Why use a medium base resin?

Ion exchange resin vs activated carbon

Activated carbon has been the preferred adsorbent for gold recovery in the Western World for the past few decades. Contrastingly, Former Soviet Union (FSU) countries have always preferred ion exchange resins, mainly employing resin-in-pulp (RIP) technology ^[1]. Ion exchange resins have several advantages over activated carbon for the recovery of gold, as discussed in a number of previous publications ^[2,4,6,7]. The main advantages are as follows:

- i. Chemical regeneration: ion exchange resins are stripped at low temperatures and do not require energy-intensive thermal regeneration, as in the case of activated carbon. This is especially relevant in remote areas where access to cheap and reliable power can be a problem.
- ii. Preg-robbing ores: some gold ores contain naturally occurring carbonaceous material which compete with activated carbon for gold, thereby reducing the recovery efficiency. Ion exchange resins show high adsorption efficiencies, even in the presence of naturally occurring carbonaceous matter.
- iii. Less prone to fouling by organics ^[9]: Diesel or kerosene can be added to the pulp to blind the “natural carbon”, but it also fouls the activated carbon adsorbent. Resins are not fouled to the same extent as activated carbon by the addition of diesel/kerosene and can be successfully used in the presence of some organic blinding agents.

The main disadvantage of gold-selective resins is that they are more expensive than activated carbon. However, despite the higher adsorbent cost, resins can be significantly more cost-effective than carbon, in both a capital and operating expense.

Medium base versus strong base resin

A number of special gold-selective resins are available on the market. These can be grouped roughly according to their functionality under strong-base and medium-base resins ^[6,7,10].

Strong-base resins, which are more commonly used for gold extraction, are not pH sensitive and operate effectively at pH values above 10.5. Due to the strong affinity of these resins for metal cyanide anions, elution of the loaded metals is more difficult and a sulphuric acid/thiourea mixture is most commonly used. Thiourea is a suspected carcinogen, resulting in reluctance by new operations to use strong-base resins. Thiourea is, however, readily oxidised and could be safely disposed of.

Medium-base resins, such as the Purolite S992, contain a mixture of quaternary, tertiary, secondary, and primary amine groups. The functional groups on medium base resins must be protonated for extraction to take place. Hence, these resins perform best at pH values between 9 and 11, with a reduction in gold loading capacity above pH 10.5. Elution of the resin is quite simple and is performed by contacting the resin with an alkali, such as sodium hydroxide. This eliminates the possibility of toxic hydrogen cyanide evolution, since the pH remains alkaline throughout the process.

Speciation of feed solution

Cyanidation is still the most widely used method to leach gold, using sodium or calcium cyanide as lixiviant. An anionic gold-cyanide complex is formed that is extractable by basic resins. Other metals present in the ore, such as silver and base metals (copper, nickel, cobalt, zinc, iron, etc.) are also leached in cyanide media. The nature of the metal-cyanide complex is dependent on the concentration of free cyanide and pH of the solution ^[1,13]. Some metals can be present in the feed as all or some of their different cyanide complexes (Table 1).

Selective ion exchange resins are designed to preferentially adsorb the mono-valent gold-cyanide species. The presence of other metals, such as $[\text{Cu}(\text{CN})_2]^-$, that form similar mono-valent cyanide-species will reduce the resin's capacity for gold. Under cyanide-deficient conditions, this type of cyanide-species is dominant, exacerbating the impact on the gold loading capacity of the resin. An ordinary ion exchange resin will become quickly exhausted with copper, leaving very little capacity for gold loading. Copper-cyanide complexes similarly load onto activated carbon, resulting in the same issues as with ion exchange resins. There is thus the need for a special gold-selective adsorbent.

The Purolite S992 is highly selective for gold over copper, which might result in a purer gold eluate/bullion for specific applications.

Table 1 Metal cyanide complexes formed

Metal	Cyanide complex
Au	$[\text{Au}(\text{CN})_2]^-$
Ag	$[\text{Ag}(\text{CN})_2]^-$
Cu	$[\text{Cu}(\text{CN})_2]^-$, $[\text{Cu}(\text{CN})_3]^{2-}$, $[\text{Cu}(\text{CN})_4]^{3-}$
Co	$[\text{Co}(\text{CN})_5]^{3-}$, $[\text{Co}(\text{CN})_6]^{3-}$
Ni	$[\text{Ni}(\text{CN})]^+$, $[\text{Ni}(\text{CN})_2]$, $[\text{Ni}(\text{CN})_3]^-$, $[\text{Ni}(\text{CN})_4]^{2-}$
Fe	$[\text{Fe}(\text{CN})_6]^{3-}$, $[\text{Fe}(\text{CN})_6]^{4-}$
Zn	$[\text{Zn}(\text{CN})_4]^{2-}$

Gold and base metal loading

A synthetic solution with a "typical high grade" pregnant leach liquor composition was used to determine the gold and base-metal loading capacities of various adsorbents. A commercial strong-base resin and coconut-based activated carbon was included with the S992, for comparison.

The tests were performed by passing a synthetic solution through a small volume of adsorbent, in a column. A large volume of solution was passed through the adsorbent bed over an extended period of time, to ensure the adsorbent was close to equilibrium with the feed solution. The loaded resins were analysed for the metals of interest. The results are listed in Table 2.

Table 2 Adsorbent loading in "high grade" solution

Metal	Metal concentration in solution, mg/L	Adsorbent loading, mg/kg		
		S992	Commercial strong base resin	Activated carbon
Au	9	4 183	9 080	16 450
Cu	13.6	not detected	525	105
Zn	1.0	96	103	233
Ni	10.4	128	1746	129

The selectivity order for these adsorbents was as follows:

S992, medium base resin: Au > Zn > Ni >> Cu

Commercial strong base resin: Au > Ni > Zn > Cu

Activated carbon: Au > Zn > Ni > Cu

The highest gold loading was achieved with activated carbon, followed by the strong base resin and then Purogold S992. All the adsorbents showed good selectivity for gold over the base metals present, but the Purogold S992 was the only adsorbent that loaded no copper. This characteristic makes the resin particularly well-suited to gold-extraction from liquors with high copper values. No gold-loading capacity will be lost to copper. Additional inventory is not required to provide for the loading of copper. Cell-house efficiency will be higher, since no copper will report to the eluate and the electrowinning circuit.

Physical characteristics of Purogold S992

Resin-in-pulp operations require an adsorbent with a reasonable size differential between that of the adsorbent particles and the pulp, for ease of separation of the loaded adsorbent and pulp. A second requirement is mechanical strength, since the adsorbent has to withstand the rather harsh conditions that exist during contact of the adsorbent and leached pulp in agitated reactors and transfer of the adsorbent between stages.

The S992 resin has a particle size of 800-1200 µm, with an average diameter of 870 µm. Gold ores are typically milled to 75% passing 75 µm. The apertures of the screens that are typically used to separate resin and pulp are 500-600 µm. The resin particles are thus roughly 800 µm larger than the gold particles, and 270 µm larger than the screen apertures, allowing easy separation via screens.

The mechanical strength of an adsorbent can be determined via a number of different laboratory-scale tests. These tests provide a quick way of comparing the relative strength of different adsorbents. The resin was subjected to a ball mill test, as executed by Mintek. During this test, a sample of the resin and steel balls are placed in a cylinder filled with water, and milled for a period of 30 minutes. After completion of the test, the fraction of resin larger than 600 µm is determined and compared with the volume of the >600 µm fraction prior to milling. This final volume, expressed as a percentage of the initial volume, provides an indication of the mechanical strength of the resin.

A mechanical strength of 96% was determined for Purolite S992, and the bead size distribution of the resin remained the same before and after milling. This compares favourably with the Dowex Minix resin (XZ 91419.00), which showed a mechanical strength of 91% under the same experimental conditions. It had been reported previously that the operational loss of the Dowex Minix resin at Penjom Mining was <5 g resin/t ore ^[7]. It can thus be assumed that the operational losses of S992 would be similar or somewhat lower.

Elution characteristics of S992

The S992 resin is eluted under alkaline conditions, using a caustic/cyanide liquor.

The elution results summarised in Table 3 and illustrated in Figure 2 were generated using resin pre-loaded with a synthetic solution that represents a "typical" pregnant leach solution after cyanidation. The resin was eluted with a mixture consisting of 20 g/L NaCN and 10 g/L NaOH, at a flowrate of 2 bedvolumes per hour.

Table 3 Elution data

Metal	Feed composition, mg/L	Resin loading, mg/kg	Volume required for elution, BV	Eluate composition ^a , mg/L
Au	8.5	4 091	8	176
Ag	1.1	92	5	4
Fe	8.7	56	2	2
Ni	9.5	97	2.5	4
Zn	1.5	1 391	2.5	61
Cu	11	0	Not loaded	0

a- Based on a total throughput of 8 bedvolumes

Complete elution of the resin was achieved within 8 bedvolumes. The base metals were eluted with less than 3 bedvolumes of eluant, while all silver was eluted within 5 bedvolumes. Further optimisation of the elution operation is required for each project and conditions will vary slightly depending on the relative ratios of gold, silver and base metals in the feed to the adsorption section. An increase in the NaOH concentration of the eluant would ensure faster gold and silver stripping, into a smaller volume of eluate. The eluted resin was analysed for residual metal content. The barren resin contained 32 g/t of gold. Other metals were below the detection limit.

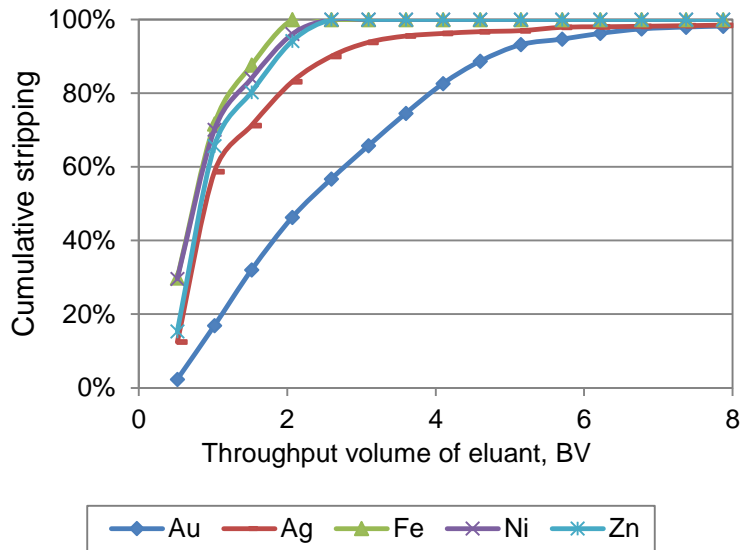


Figure 2 Elution of S992: cumulative

The ease of elution of the S992 resin gives it a further advantage over activated carbon and strong base resins, in addition to its exceptional selectivity for gold over copper. The main elution conditions for each adsorbent are listed in Table 4.

Table 4 Elution characteristics of different adsorbents compared

	S992	Commercial strong base resin	Activated carbon
Eluant	NaOH/NaCN	H ₂ SO ₄ /thiourea	NaOH/NaCN
		<i>Thiourea is a suspected carcinogen; Evolution of toxic HCN under acidic conditions; requires scrubbing</i>	
Elution temperature	60 °C	60 °C	110-130 °C
			<i>Energy intensive; Elution in pressure vessel.</i>
Scale treatment	<i>Acid wash of resin may be required to remove scale; HCN evolution</i>	<i>No additional acid wash required to remove scale.</i>	<i>HCl wash of loaded carbon to remove scale; HCN evolution</i>
Regeneration	none	none	Thermal regeneration at 700-800 °C
			<i>Energy intensive</i>

CONCLUSIONS

Various processes have been suggested and implemented to allow the economic exploitation of complex gold ore bodies. The increased complexity of ore-bodies that will be mined in the future warrants a thorough investigation into the various options available, at the start of the project. Technical, health and safety, and economic aspects of different flowsheets must be considered.

The S992 resin can be used with success to recover gold from ore bodies with high copper contents, due to its exceptional selectivity for gold over copper. Good gold upgrades can be achieved onto the resin and a high-purity bullion can be produced.

This resin is easily eluted with an alkaline mixture of sodium cyanide and sodium hydroxide, at low temperatures. It does not require energy intensive thermal regeneration, such as activated carbon. Alkaline conditions are always maintained. The elution reagents are considered benign, when compared to the acidic/thiourea elution required by gold-selective strong base resins.

The resin can be used in a stand-alone resin-in-pulp operation or combined with special cyanide recovery processes, such as SART.

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