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COMPARISON OF GOLD-SELECTIVE ION EXCHANGE RESINS AND ACTIVATED CARBON FOR THE RECOVERY OF GOLD FROM COPPER-GOLD LEACH LIQUORS

By

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ABSTRACT

A large portion of hitherto unexploited gold is associated with cyanide-soluble copper minerals. The presence of copper in cyanide leach operations causes various operational problems, including increased cyanide consumption, increased toxicity of effluent and potentially lower gold recoveries. Changes to the “traditional” gold processing flowsheet and operating conditions are required to ensure maximum gold recovery at minimum operating expense.

Testwork was conducted to compare the efficacy of different types of adsorbents for gold recovery from solutions containing appreciable copper values. The effect of variations in solution chemistry, primarily pH and copper concentration, on the gold-loading capacity and selectivity for gold over copper of activated carbon (Haycarb coconut based), a strong-base (Purolite A194) resin, and medium-base (Purogold S992) gold selective resin was investigated. The ease with which the loaded gold could be eluted from the adsorbent and the ability to effect gold/copper separation via split elution was also compared. Based on the results obtained, the effect of adsorbent choice upon plant design was evaluated.

INTRODUCTION

Volatile gold prices in the face of rising costs for mining and refining is forcing mines to look for new ways to reduce costs and increase recoveries. It has been estimated that about 20% of all gold deposits contain significant copper mineralisation^(1,7). Many ore-bodies remain undeveloped^(9,12), due to the possible metallurgical and environmental issues caused by the formation of base-metal cyanide complexes. As the 'easy' ore-bodies are being depleted, the focus is turning to these previously undeveloped deposits.

The recovery of gold from gold-copper deposits is associated with certain operational problems, such as the dissolution of copper minerals in cyanide lixiviant, resulting in high reagent consumption and cost. 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. The chemistry of copper leaching in cyanide liquor, as well as associated issues around selective gold recovery, is discussed briefly below.

THEORETICAL BACKGROUND

Copper Speciation in Cyanide Leach Liquors

The majority of copper minerals, including copper oxides, carbonates, sulphides (with the exception of chalcopyrite) and native copper, are highly soluble in cyanide solutions^(2,3,4). This can have a detrimental effect on the process efficiency and economics due to high cyanide consumption, reduced gold leach rates and poor gold recovery.

Cyanidation of copper minerals results in the formation of cuprous cyanocomplexes, i.e. $[\text{Cu}(\text{CN})_{x+1}]^{x-}$ where x varies from 1 to 3^(4,11). The dissolution of copper present in the ores as the cupric (Cu(II)) is described by Reactions 1 to 4 below.



Firstly, Cu(II) reacts with cyanide and forms insoluble yellow cupric cyanide (Reaction 1), which quickly decomposes into white cuprous cyanide and cyanogen (Reaction 2). Cuprous cyanide is dissolved further in the presence of an excess of free cyanide, forming colourless copper-cyanide complexes (Reaction 3). Cyanogen, which is soluble in water, reacts under alkaline conditions as shown in Reaction 4, forming cyanate. The formation of cyanate consumes cyanide to form a specie that is difficult to decompose.

According to the Pourbaix diagram for the "copper-cyanide-water" system⁽¹³⁾ presented in Figure 1 under typical gold cyanidation conditions (pH 10-11, Eh -0.2 – 0.2 V, excess of free cyanide), copper is mainly present as the double- and triple-charged anionic cuprous cyanocomplexes $\text{Cu}(\text{CN})_3^{2-}$ and $\text{Cu}(\text{CN})_4^{3-}$.

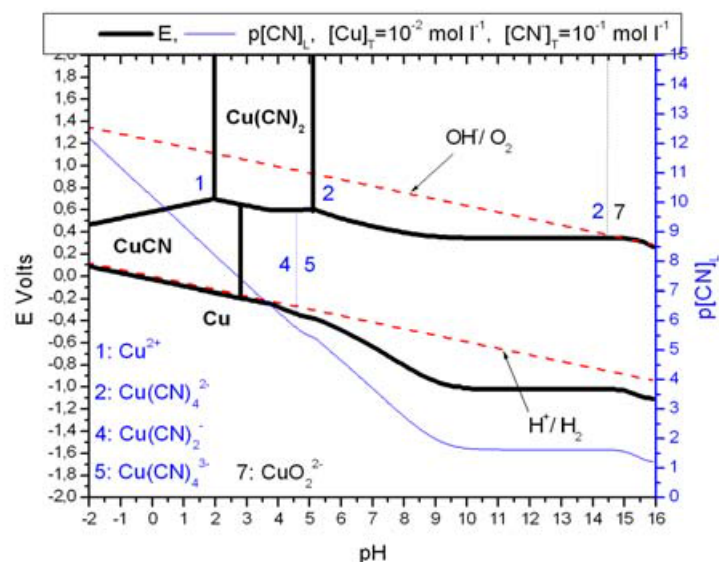


Figure 1: Eh-pH diagram for the Cu-CN-H₂O system at 25 °C ⁽¹³⁾

The speciation of copper is a function of the pH and free CN concentration of the liquor ^(10,14). According to Figure 2 and Figure 3, at high pH (>10) and a free CN- concentration of >150 mg/L, approximately 80-90% of copper should be present as Cu(CN)₃²⁻ complex and ~10-20 % as Cu(CN)₄³⁻ specie.

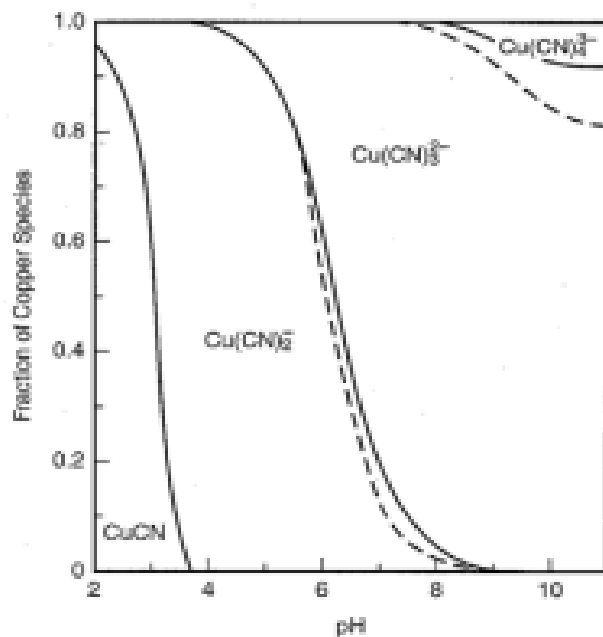


Figure 2: Effect of pH on copper (I) speciation at CN-to-Cu ratio of 25 ⁽⁴⁾

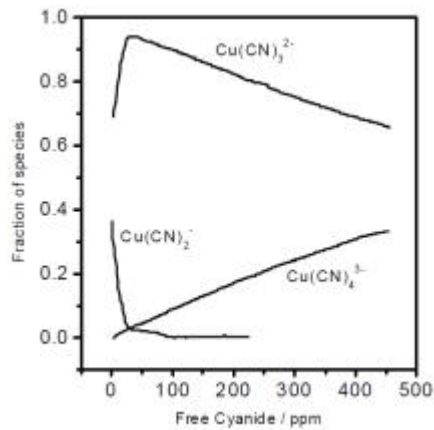
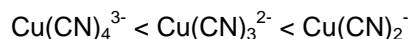


Figure 3: Effect of free cyanide concentration on Cu(I) speciation at 10 mg/L Cu and pH 10⁽⁴⁾

Gold Recovery Via Activated Carbon from Cyanide Liquors Containing Cuprous Cyanocomplexes

Activated carbon is widely used for gold recovery from cyanide leach liquors via carbon-in-leach (CIL) or carbon-in-pulp (CIP) technology. From all the base metals cyanide complexes typically present together with gold in the leach liquor, only copper, and to a lesser extent nickel, are loaded onto activated carbon⁽⁶⁾.

The loading behaviour of copper cyanide onto activated carbon depends on the copper speciation and increases in the following order^(1,12):



Marsden and House⁽¹²⁾ stated that copper concentrations as low as 100 mg/L can interfere severely with the gold adsorption processes onto carbon. The molar ratio of cyanide to copper should be maintained at or above 4:1 in the leach solutions prior to feeding the carbon adsorption processes in order to minimize the formation of Cu(CN)_2^- complexes. CIP application for materials containing high concentrations of cyanide-soluble copper may be unsuitable because it requires very careful control of pH and cyanide concentration.

Copper loads onto carbon to a certain extent even when adequate levels of free cyanide is maintained in solution, and the amount of loaded copper is often equivalent to or greater than the amount of gold loaded. However, copper could be eluted from the carbon with cyanide solution at room temperature prior to gold elution at high temperature⁽⁵⁾.

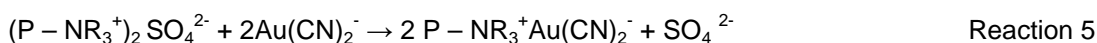
Gold-Selective Ion Exchange Resins

While the Western World has been slow in adopting IX resins for gold recovery, several operations have successfully implemented the use of resin-in-pulp/resin-in-leach (RIP/RIL) in recent years. These include Avocet Mining's Penjom Gold Mine in Malaysia and Anglo Asia's Gedabek mine in Azerbaijan. In most cases, the choice of adsorbent was forced by the complex nature of the ore which made the use of activated carbon uneconomical. The main advantages of using resin over carbon are:

- Improved gold recoveries from preg-robbing ores;
- Better selectivity for gold over base metals, including copper;
- Simple and energy-efficient elution/regeneration.

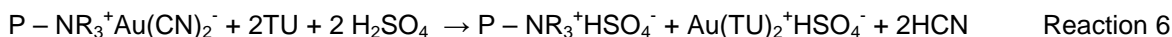
A number of special gold-selective resins are available on the market. These can be grouped roughly according to their functionality under strong-base and medium-base resins^(8,9).

Strong base anion (SBA) exchange resins are more commonly used for gold extraction. These resins generally contain quaternary ammonium functional groups with fixed positive charges. The gold loading efficiency of these resins is not pH sensitive and they operate effectively across the entire pH range. The loading of gold-cyanide onto the resin is depicted in Reaction 5.



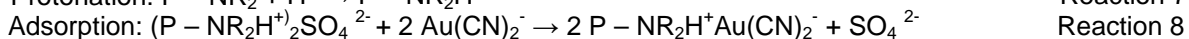
Where P represents the polymer matrix and R an alkyl chain

Due to the strong affinity of these resins for gold-cyanide anions, elution of the loaded precious metals is difficult and a sulphuric acid/thiourea mixture is most commonly used. During elution, the negatively charged gold-cyanide complex is broken and a positively charged gold-thiourea complex is formed, as shown in Reaction 6. The resin has no affinity for the positively charged gold-thiourea complex and the gold reports to the eluate stream.



A disadvantage of the use of SBA resins for gold cyanide recovery is the fact that 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. Another disadvantage is that thiourea decomposes relatively quickly in acidic solution. One of the degradation products is elemental sulphur which may form scum during elution and have a detrimental effect on the electrowinning process.

Medium base resins contain a mixture of tertiary, secondary, and primary amine groups. Commercial examples are the PuroLite S992 and BASF's Aurix (with guanidine functionality). The functional groups on medium base resins must be protonated for extraction to take place, as depicted in Reactions 7 and 8. Hence, these resins perform best at pH values between 9 and 11, with a reduction in gold loading capacity above pH 10.5.



The extent of amine protonation at a specific pH is determined by the basicity, or pKa value, of the functional group on the resin. The effect of the basicity of the functional group on loading and elution of different anion exchange resins⁽⁸⁾ is illustrated in Figure 4.

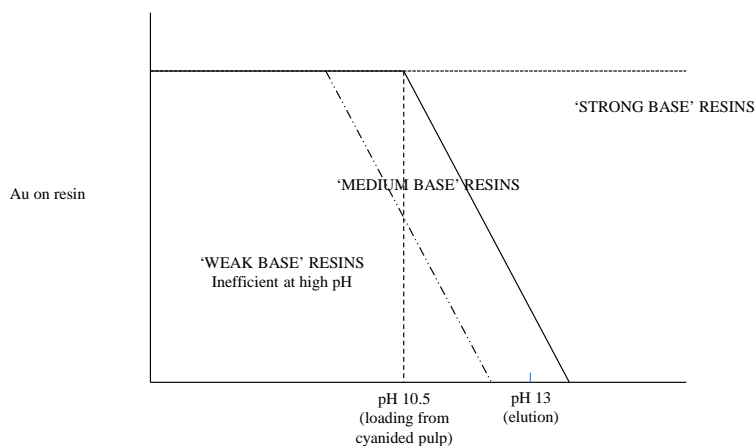


Figure 4: Effect of functional group basicity on the degree of protonation and gold loading⁽⁸⁾

Elution of the resin is quite simple and is performed by contacting the resin with an alkali, such as sodium hydroxide. The alkali causes deprotonation of the resin, thereby removing the positive charge. The now-neutral resin has no affinity for the metal-cyanide complex and releases it. The use of an alkali for elution ensures that the pH remains alkaline throughout the adsorption and elution processes, thereby eliminating the possibility of toxic hydrogen cyanide evolution. This is a big advantage, from a health and safety point of view.

TEST RESULTS

Three different adsorbents were tested, namely:

- Haycarb coconut-based activated carbon;
- Purolite A194, a gold-selective strong base resin;
- Purogold S992, a gold-selective medium base resin.

The resins were converted to the sulphate form prior to adsorption tests by contacting it with 2 bedvolumes (BV's) of a 1 M Na₂SO₄ solution in a column, at a flowrate of 2 BV/h (a bedvolume is equal to the volume of resin used). Excess reagent was rinsed from the resin with 4 BV's of water in plug wash.

Synthetic solutions were prepared using deionised water, and salts of sodium cyanide (NaCN), cupric sulphate (CuSO₄.5H₂O), and gold potassium cyanide (KAuCN₂). The pH of the solutions was maintained at the desired level using 1 M NaOH.

Copper and gold were analysed via Atomic Adsorption Spectroscopy (AAS).

Effect of pH on Copper and Gold Loadings of the Medium-Base Resin, Purogold S992

The effect of pH on the copper and gold loading capacity of the Purogold S992 was investigated in the pH range of 9.5 to 11. A solution containing 4 mg/L Au and 950 mg/L Cu was used. The final free cyanide concentrations were determined to be between 150 and 200 mg/L, via titration. Resin and solution were contacted in batch, at a solution:resin ratio of 1000:1 (v/v) at ambient temperature for a period of 24 hours.

The results are depicted graphically in Figure 5. As expected, both gold and copper loadings decreased with an increase in pH from pH 9.5 to pH 10.6. The copper loading decreased more substantially than the gold loading in this pH range. This indicated that the selectivity of the resin for gold over copper increased with an increase in solution pH. The optimum pH to ensure maximum gold loading and minimum copper co-loading for this resin was between 10.4 and 10.5.

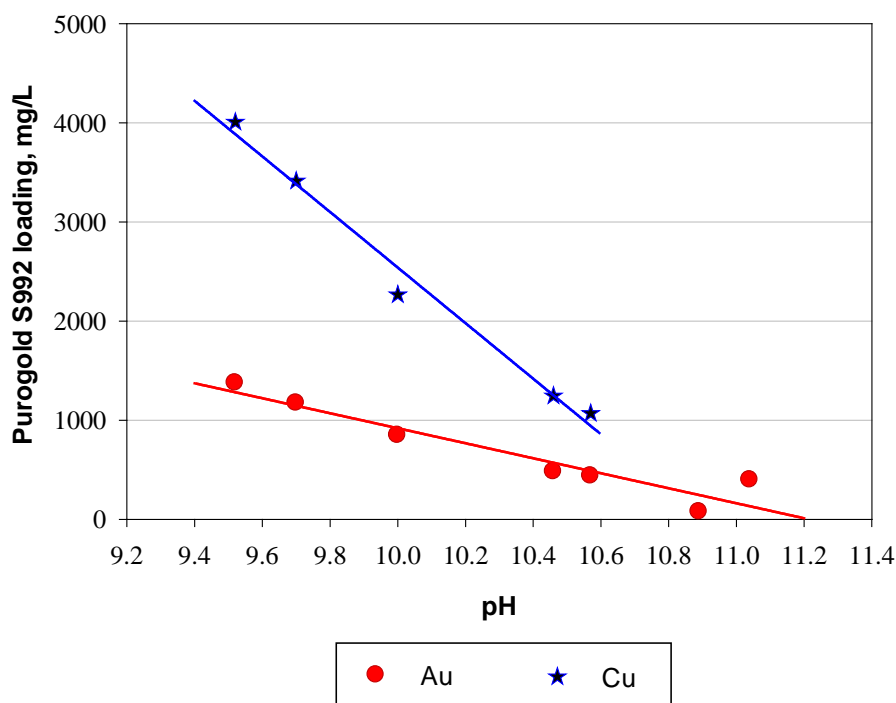


Figure 5: Effect of pH on Cu and Au loading for Purogold S992

Equilibrium Loading Isotherms for Copper and Gold

Equilibrium loading isotherms for copper and gold were generated for the three different adsorbents. The feed solution contained ~920 mg/L copper and 5 mg/L Au. The free cyanide concentration was determined to be between 150 and 200 mg/L, via titration. Portions of adsorbent and solution were contacted in batch for a period of 24 hours, at varying solution:adsorbent ratios. The results are shown graphically in Figure 6 (activated carbon), Figure 7 (Purogold S992), and Figure 8 (A194). Both copper and gold loadings are depicted relative to the gold concentration of the solution on the x-axis, for ease of reference. The copper loading was fairly constant for both carbon and Purogold S992 resin, regardless of the gold loading, while it decreased roughly linearly with an increase in gold loading for the A194 resin.

Favourable isotherms were obtained for the two ion exchange resins, Purogold S992 and A194, but the carbon gold loading isotherm was unfavourable.

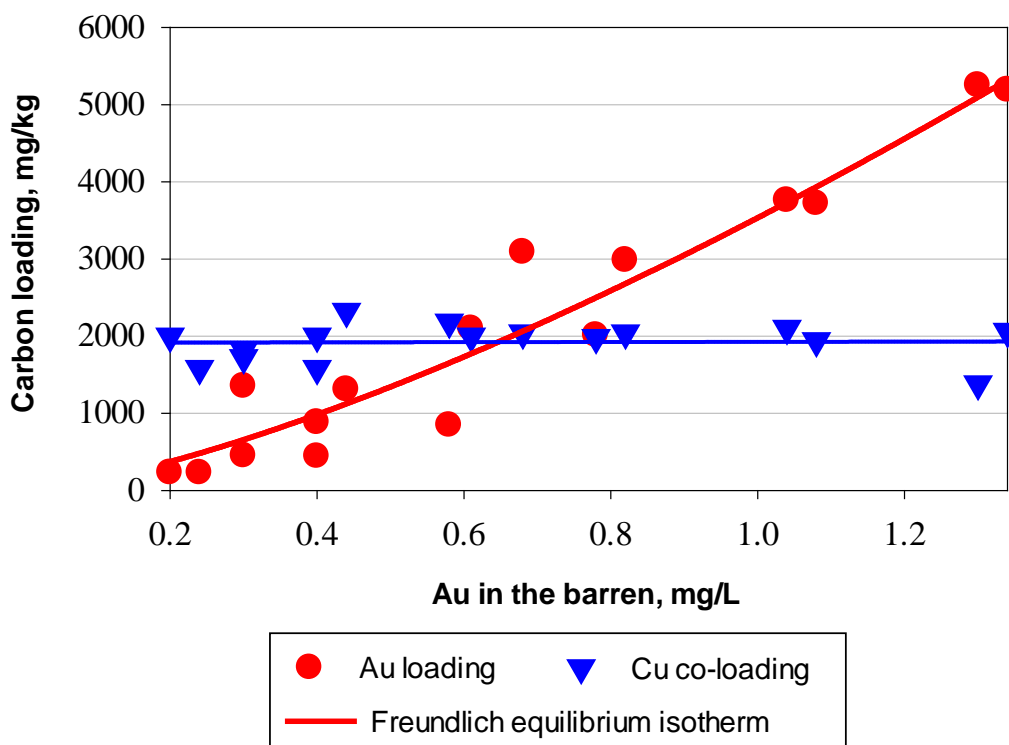


Figure 6: Equilibrium loading isotherms for Cu and Au onto Haycarb

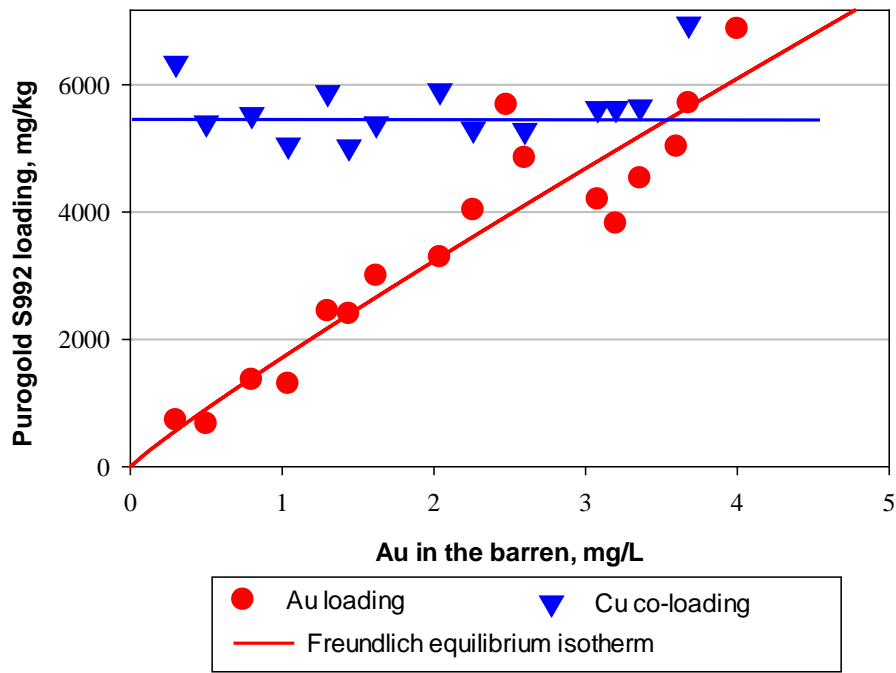


Figure 7: Equilibrium loading isotherms for Au and Cu onto Purogold S992

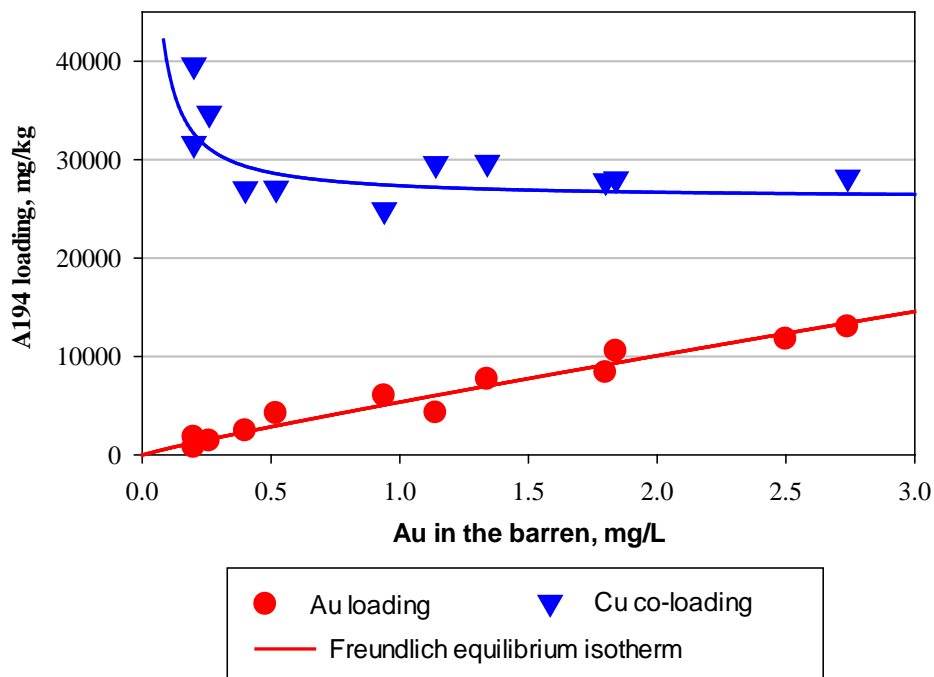


Figure 8: Equilibrium loading isotherms for Au and Cu onto A194

Freundlich isotherms were fitted to the gold equilibrium adsorption data. The Freundlich equation (Equation 1) is described as follows:

$$Y = a X^b \quad \text{Equation 1}$$

where:

Y= the equilibrium loading (mg/L or mg/kg)

X= the equilibrium solution concentration (mg/L)

a= Freundlich constant, a measure of the affinity of the metal ion for the adsorbent

b= Freundlich constant, a measure of the heterogeneous interaction of the metal with the adsorbent

The gold upgrade and selectivity of the adsorbent for gold over copper were calculated using Equations 5 and 6, respectively.

$$\text{Upgrade} = \frac{[\text{Au}]_{\text{adsorbent}} \text{ (mg/kg)}}{[\text{Au}]_{\text{solution}} \text{ (mg/L)}} \quad \text{Equation 2}$$

$$\text{Selectivity}_{\text{Au/Metal}} = \left(\frac{[\text{Au}]_{\text{adsorbent}}}{[\text{Au}]_{\text{barren}}} \right) \times \left(\frac{[\text{Metal}]_{\text{solution}}}{[\text{Metal}]_{\text{adsorbent}}} \right) \quad \text{Equation 3}$$

The behaviour of the three adsorbents was compared for a solution containing 1.4 mg/L gold and ~1 g/L copper. The selectivity coefficients for gold over copper, gold upgrades and loadings, as well as Freundlich isotherm constants for each adsorbent are listed in Table 1.

Table 1 Comparison of equilibrium loading data

Parameter	Unit	Carbon	Purogold S992	A194
Au in solution	mg/L	1.4		
Cu in solution	mg/L	1000		
Au upgrade		4000	1773	5197
Au loading	mg/kg ^a	6150	2335	7276
	mg/L	na	747	2692
Cu co-loading	mg/kg ^a	4000	5500	28000
	mg/L	na	1760	10360
Selectivity, Au/Cu		1200	422	204
Freundlich isotherm parameters				
a		3535	1844	5551
b		1.4	0.85	0.84
R ²	%	93	87	96

a – adsorbent density: carbon = 0.5 kg/L, Purogold S992 = 0.32 kg/L, A194 = 0.37 kg/L

The order of selectivity for gold over copper for the three adsorbents was:

$$\text{Carbon} > \text{Purogold S992} > \text{A194}$$

However, in spite of the higher selectivity of carbon, the gold loading was higher for the strong base resin, with the order of loading being:

$$\text{A194} > \text{carbon} > \text{Purogold S992}$$

Indicative Adsorption Plant Size Comparison

The data generated was used in a McCabe-Thiele construction to predict the adsorbent flow that would be required for efficient gold recoveries. The input parameters are listed in Table 2.

Table 2: Input parameters for McCabe-Thiele construction

Main parameter	unit	Value
Au in feed	mg/L	5
Cu in feed	mg/L	1000
Au in barren	mg/L	0.008
Residual Au on eluted adsorbent	mg/kg	50
Number of adsorption stages		7
Extraction efficiency	%/stage	75
Gold recovery within 7 stages, target	%	99.8
PLS flowrate	m ³ /h	100

The McCabe-Thiele constructions for the three adsorbents are provided in Figure 9 (activated carbon), Figure 10 (Purogold S992) and Figure 11 (A194). The indicative design parameters for the gold adsorption circuit, as obtained from the McCabe-Thiele constructions, are listed in Table 3.

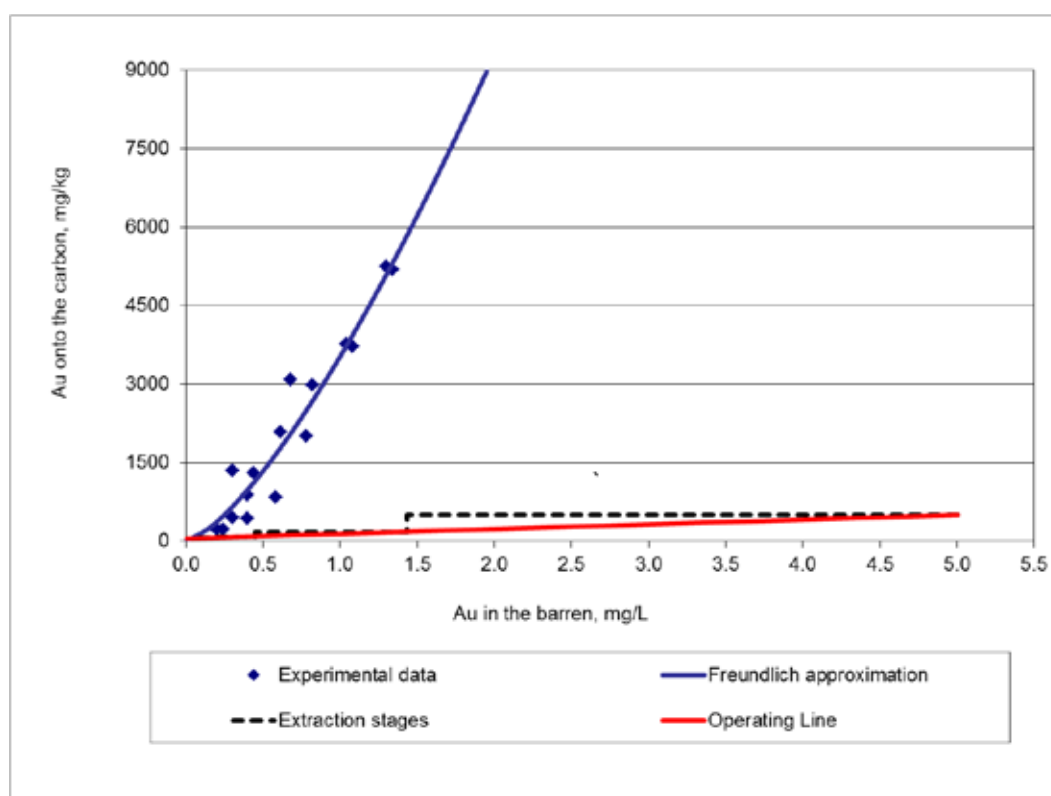


Figure 9: McCabe-Thiele construction: carbon

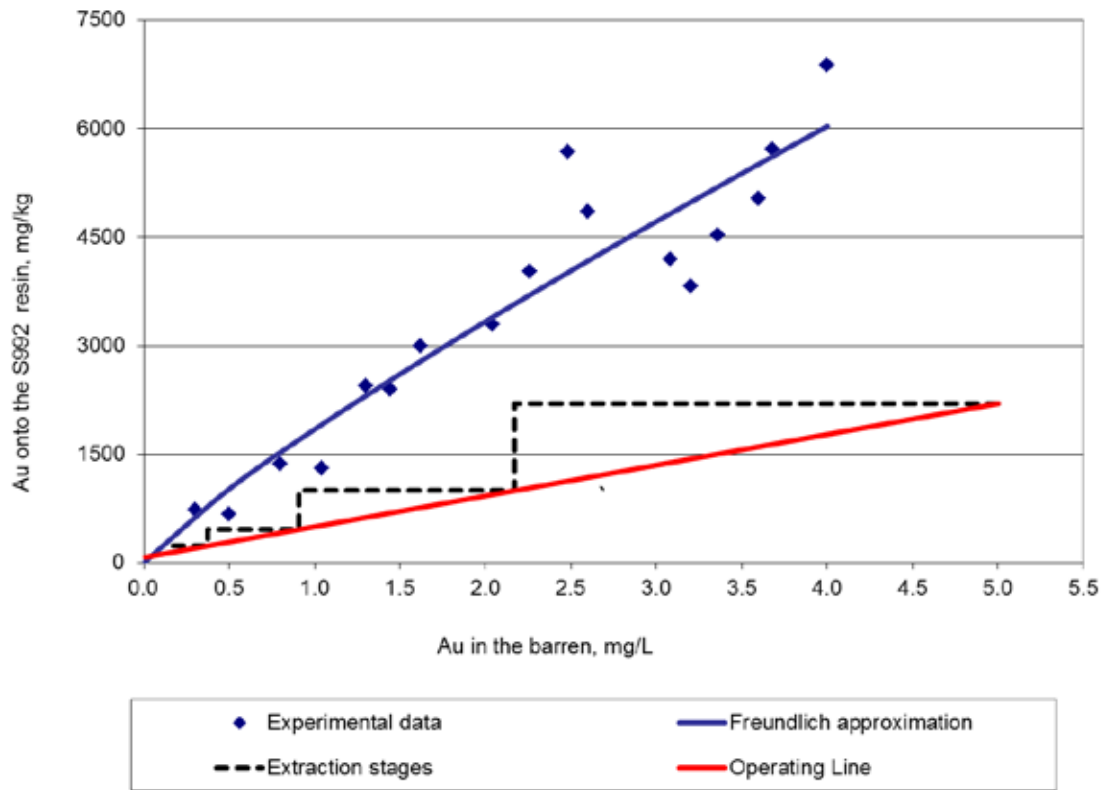


Figure 10: McCabe-Thiele construction: Purogold S992

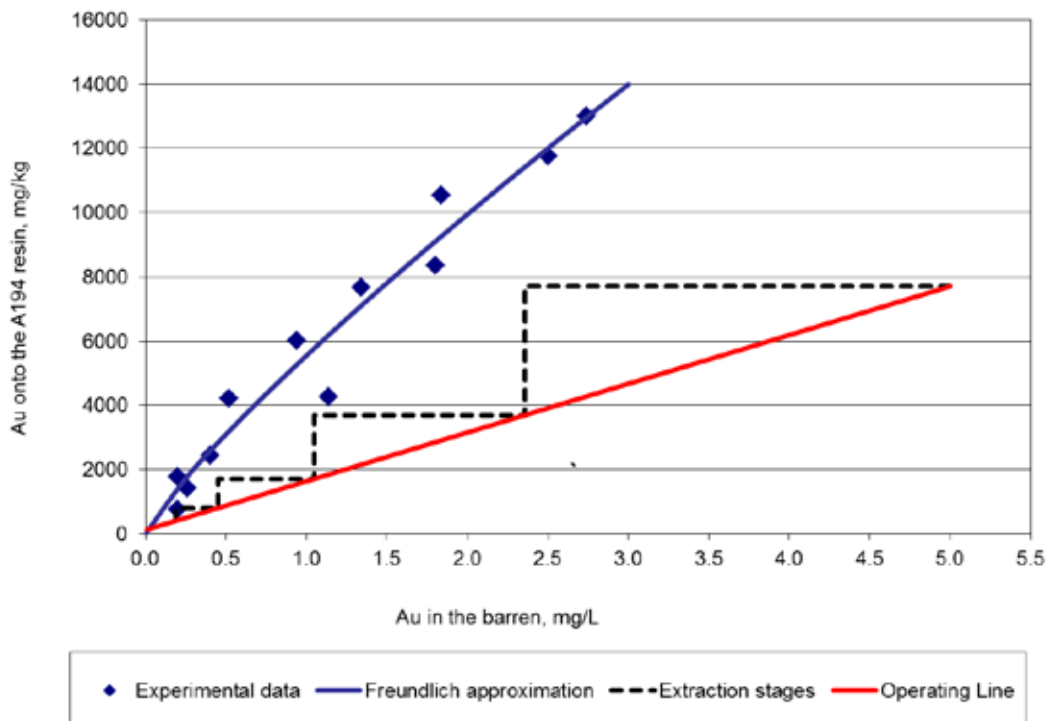


Figure 11: McCabe-Thiele construction: A194

Table 3: Indicative design parameters for gold adsorption circuit

Parameter		Carbon	Purogold S992	A194
Au loading	mg/kg	500	2200	7700
Cu loading	mg/kg	4000	5500	24300
Au in barren, exit Stage 7	mg/L	0.008	0.008	0.008
Au flow	g/h	500	500	500
Cu flow	kg/h	100	100	100
Adsorbent flow	t/h	1.0	0.23	0.06
	m ³ /h	2.0	0.71	0.18
Adsorbent unit cost	US\$/t	2200	40625	18919
Inventory cost (relative, based on inventory required for Au recovery over 24 hour period)		1	4.2	0.56
Au recovery in 7 stages	%	99.8	99.8	99.8
Cu co-extraction in 7 stages	%	4.0	1.3	1.6

The most favourable results were achieved with the A194 resin. It provided the highest gold loading, with the lowest adsorbent inventory and low copper co-loading. Due to the unfavourable isotherm of activated carbon, the gold loading at low concentrations was severely depressed.

Resin is more expensive per unit than activated carbon. The cost of the inventory for the A194 would be about half of that of activated carbon, but a much higher capital outlay will be required for the first fill of the Purogold S992. However, several previous costing studies^(9,16) have shown that significant savings can be realised for resin relative to carbon when the cost of the entire metallurgical plant is taken into account. The capital outlay for a resin plant is typically 20-30% cheaper than carbon, while the operating savings is 40-50%. The major factor that contributes to the cost of an activated carbon plant is the fact that it requires thermal regeneration in a kiln at temperatures of 700-800 °C.

Effect of Copper Concentration on Gold Loading

Previous work⁽¹⁵⁾ showed that the Purogold S992 loaded no copper from a 'typical' gold leach liquor. In addition to copper (11 mg/L) and gold (8.5 mg/L), the 'typical' feed solution also contained 1.1 mg/L silver, 8.7 mg/L iron, 9.5 mg/L nickel and 1.5 mg/L zinc. The gold loading obtained was 4091 mg/kg and no copper co-loading was detected. This result prompted further work to determine the selectivity of this resin for gold over copper over a wider range of copper concentrations. The carbon and A194 resin were subjected to the same tests, for comparison.

Solution and adsorbent were contacted in batch in a solution:adsorbent ratio (volume/volume for resin and volume/mass for carbon) of 1000:1 at ambient temperature for a period of 24 hours. The feed liquor contained 5 mg/L gold and copper varying from 1 to 5 g/L. The results are depicted graphically in Figure 12 (copper loading vs copper in solution) and Figure 13 (gold loading vs copper in solution).

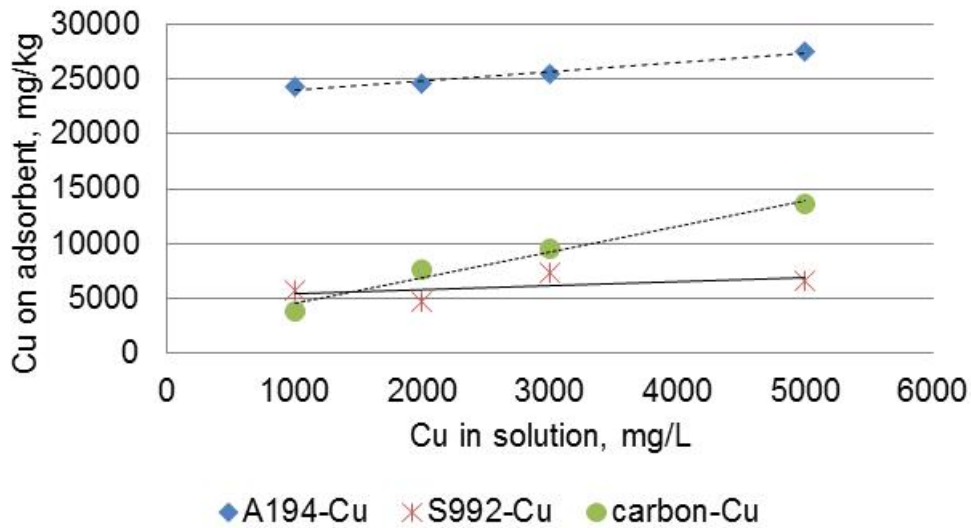


Figure 12: Effect of copper in feed (1-5 g/L) on copper loading

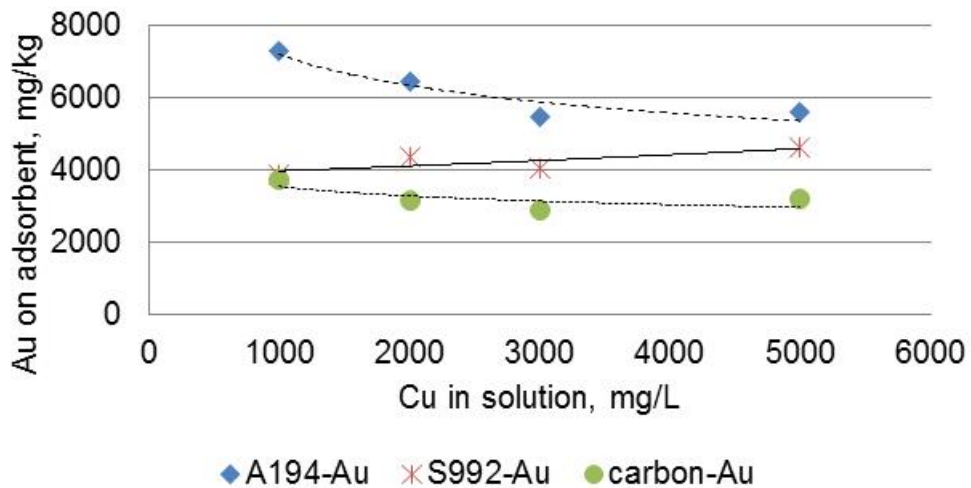


Figure 13: Effect of copper in feed (1-5 g/L) on gold loading

The gold loading onto both activated carbon and A194 decreased with an increase in copper-in-solution from 1 to 5 g/L, with a simultaneous increase in the copper loading. The performance of the Purogold S992 was largely unaffected by the increase in the copper concentration of the feed, with fairly stable copper and gold loadings. Additional investigations should include the range of copper concentrations between 10 and 1000 mg/L, to determine the copper concentration at which the resin starts to load copper.

Elution Characteristics of Purogold S992

The efficiency of elution of copper and gold from the Purogold S992 was investigated by elution in a column, using a mixture of 20 g/L NaCN and 10 g/L NaOH. The flowrate was maintained at 2 BV/h and the temperature at 60 degrees Celcius. The eluate was collected in roughly 1 BV fractions. The resin had been pre-loaded to contain 2.4 g/L gold and 3.3 g/L Cu. The results are depicted graphically in Figure 14.

Complete elution of copper was achieved within approximately 8 bedvolumes, while complete gold elution was achieved within 12 bedvolumes.

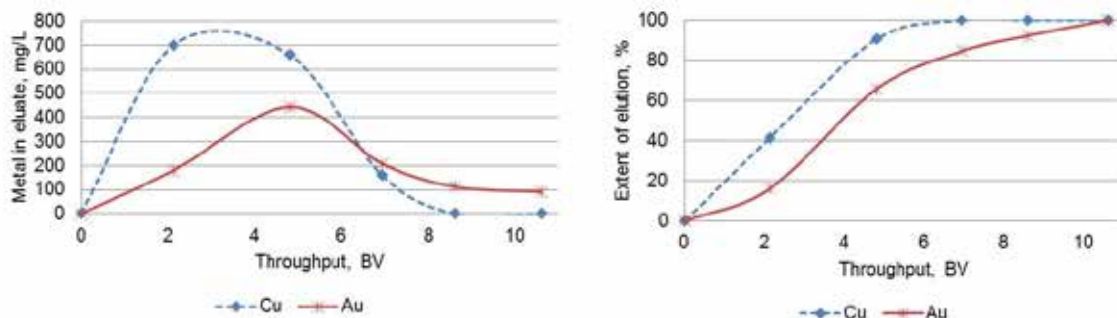


Figure 14: Elution profiles for Purogold S992, Cu and Au

The effect of NaOH concentration was further investigated in more detail, to determine the conditions required to obtain a split between copper and gold. Portions of the pre-loaded resin (containing 2.4 g/L gold and 3.3 g/L copper) was contacted in batch at ambient temperature over a period of 24 hours with 10 bedvolumes of solution. The solutions contained 5 g/L NaCN and varying concentrations of NaOH (0.04 to 4 g/L). The NaCN concentration was based on the total loading of gold plus copper, ensuring an excess of cyanide was present. The extent of metal elution at different NaOH concentrations is shown in Figure 15.

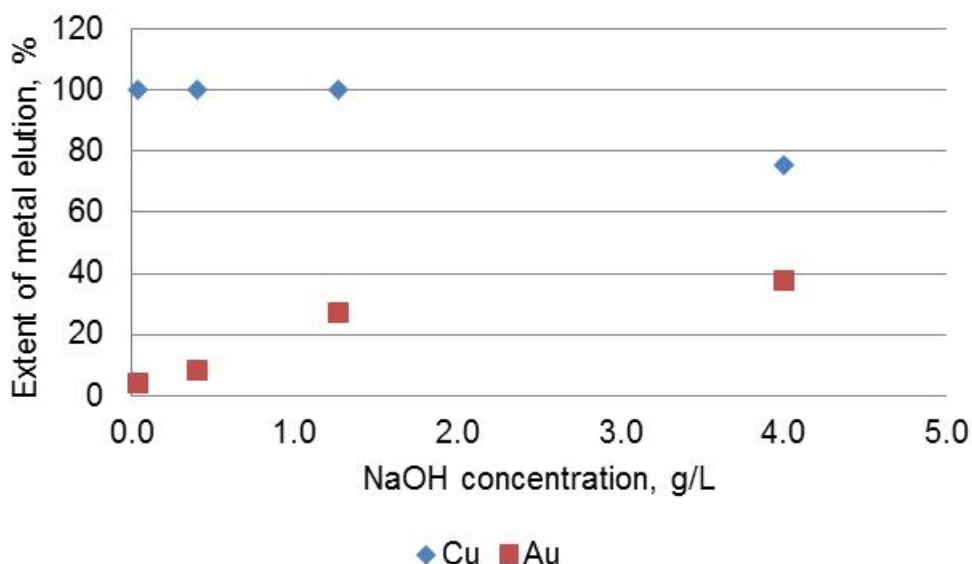


Figure 15: Effect of NaOH on Cu and Au elution from Purogold S992

Complete copper elution was achieved at NaOH concentrations of 0.04 to 1.3 g/L. Above 1.3 g/L NaOH, the extent of copper elution dropped. Simultaneous elution of gold was as low as 8% at a NaOH concentration of 0.4 g/L.

The decrease in copper elution efficiency at higher NaOH concentrations (4 g/L) is of interest and corresponds to observations by Fleming & Cromberg⁽⁵⁾. They reported that the rate of the gold elution from weak-base resins increases with sodium hydroxide concentration up to 0.5 M NaOH and then decreases. They suggested that the poorer gold stripping efficiency could be due to precipitation of the weaker metal-cyanide complexes (such as copper) as hydroxides within the pores of the resin, resulting in physical entrapment of the metal in the resin.

These results indicate that it should be possible to selectively elute copper prior to gold, by maintaining a suitably low NaOH concentration. The concentration of cyanide should be maintained at an adequate level to prevent precipitation of copper-hydroxide. Optimum conditions would depend upon the specific gold and copper loadings of the resin and should be optimised for the specific application. Suggested conditions to obtain a split elution are:

- Step 1, to elute copper: ambient temperature, 20 g/L NaCN, 1 g/L NaOH;
- Step 2, to elute gold: 60 °C, 20 g/L NaCN, 10 g/L NaOH.

Elution Characteristics of A194

The efficiency of elution of the strong base resin, A194 was investigated by eluting a portion of pre-loaded resin in a column. The resin was pre-loaded in batch with a synthetic solution to contain 4.97 g/L gold and 2.4 g/L copper. A two-step elution was done, in an attempt to elute copper prior to gold. Conditions were:

Step 1: 60 °C, 5 BV's of 0.3 mol/L H₂SO₄;

Step 2: 60 °C, 10 BV's of an acidic thiourea mixture (0.5 mol/L H₂SO₄ and 1 mol/L SC(NH₂)₂).

Cumulative elution curves for gold and copper are shown in Figure 16. The copper cyanide species was not eluted with sulphuric acid. This may be due to the formation of insoluble CuCN under acidic conditions. However, copper was eluted slightly before gold with 1 M acidic thiourea. It is suggested that a more definite split will be obtained by following a two-step elution, using a dilute thiourea solution to target copper first, followed by a more concentrated thiourea solution to elute gold. Complete elution of both copper and gold was achieved within approximately 10 BV's of acidic/thiourea solution.

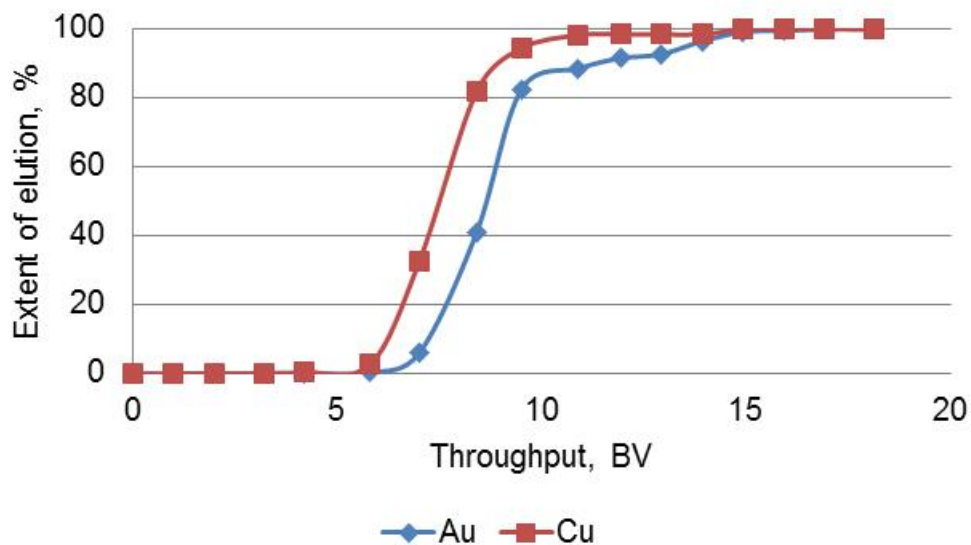


Figure 16: Elution profile for A194, Au and Cu

The elution and regeneration procedure for all three adsorbents are summarised below, for ease of comparison. Specific conditions may vary for different projects, but the main aspects are universal.

Table 4: Elution and regeneration procedures compared

	Activated carbon Coconut-based	Purogold S992 Medium-base IX resin	A194 Strong-base IX resin
Reagent	NaOH/NaCN	NaOH/NaCN	Sulphuric acid/thiourea
			Thiourea is a suspected carcinogen; Evolution of toxic HCN requires scrubbing.
Elution temperature	110 – 150 °C	60 °C	60 °C
	High temperature requires a pressure vessel.		
Split elution to selectively elute Cu and gold	possible		
Regeneration	Thermal: 700 – 800 °C	none	none
	Energy intensive		

CONCLUSIONS

Three different adsorbents were evaluated for the recovery of gold from gold-copper ores, i.e. Haycarb coconut-based activated carbon, a medium-base ion exchange resin, Purogold S992, and a strong base anion exchange resin, Purolite A194.

The metal loading onto Purogold S992 is pH-sensitive, as expected from a medium-base resin. Both gold and copper loadings decreased with an increase in pH from 9.5 to 11. The optimum pH of operation, allowing maximum gold loading and minimum copper co-loading, was found to be at pH 10.4 – 10.5.

Activated carbon and A194 showed an increase in copper co-loading and decrease in gold loading when the concentration of copper in the feed was increased from 1 to 5 g/L (Au in the feed was 5 mg/L). Under the same conditions, the copper and gold loadings for the Purogold S992 were largely unaffected.

The gold-loading ability of carbon was severely depressed at low gold concentrations, as would be found in the last stage of a CIP circuit. A rough comparison of the adsorption circuit inventory requirement of the three adsorbents showed that the flowrate of activated carbon should be ~4 times higher than that of Purogold S992 and ~16 times higher than the A194 to achieve the same low barren gold concentrations of 0.008 mg/L.

It is possible to apply special elution conditions for all three adsorbents to obtain a certain extent of selective elution of the copper prior to gold. Efficient elution to a residual gold content of <50 mg/kg is possible for all three adsorbents. Activated carbon and Purogold S992 are eluted under alkaline conditions with a mixture of NaCN and NaOH, while an acidic thiourea mixture is required to elute gold from the A194. The biggest distinguishing factor in elution/regeneration of the different adsorbents is the energy intensive, and costly, thermal regeneration required by carbon while resins require no regeneration. This results in a significant capital and operating saving when using ion exchange resins.

Every project should be evaluated on its own merits to determine the optimum adsorbent. The study should include testwork on different adsorbents to determine the relative performance of the various adsorbents available. The choice will be based on a combination of factors, including, but not limited to: gold and copper concentrations in the pregnant leach liquor, gold loading, co-loading of copper and other base metals, size and cost of inventory, ease of achieving desirable barren levels,

elution efficiency, extent of split obtainable between the different loaded metals during elution, reagent cost, environmental impact of reagents, and energy efficiency.

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