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THE EFFECTIVENESS OF ADSORBENTS FOR SELECTIVE RECOVERY OF GOLD FROM COPPER-BEARING CYANIDE LEACH SOLUTIONS

BAKIR İÇEREN SİYANÜR LİÇİ ÇÖZELTİLERİNDEN ALTININ SEÇİMLİ OLARAK KAZANIMINDA ADSORBANLARIN ETKİNLİĞİ

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ABSTRACT

Recovery of gold from copper-rich gold ores has proved challenging. Dissolved copper in cyanide-deficit leach solutions severely interferes with adsorption of gold onto activated carbon or ion exchange resins resulting in low recoveries. In this study, the efficiency of different adsorbents for selective recovery of gold from the copper-containing cyanide leachate was investigated. Activated carbon (NORIT GAC 1240), mixed base (Purogold A193), strong base (Dowex 21K XLT, Purogold A194) and weak base (Purogold S992) resins were tested as the adsorbents. The pregnant leach solution (PLS), which contained 28.2 mg/L Au and 2804 mg/L Cu was obtained by the cyanidation of a roasted copper-rich gold ore. The activated carbon showed a superior capacity for gold loading, followed by Purogold S992. On the other hand, Purogold S992 (weak base) achieved the highest degree of selectivity for gold over copper with the lowest copper adsorption. Mixed and strong base resins had the highest copper loadings. These findings demonstrated that Purogold S992 could be suitably used for selective recovery of gold from leach solutions containing a high level of copper.

Anahtar Sözcükler:
Bakırca zengin altın cevheri,
Siyanür liçi,
İyon değiştirici reçine,
Aktif karbon,
Seçimlilik.

ÖZ

Bakır içeriği yüksek altın cevherlerinden altın kazanımınında bazı zorluklar yaşanmaktadır. Siyanür derişimi düşük liç çözeltilerindeki çözünmüş bakır, altının aktif karbon veya iyon değiştirici reçinelere adsorpsiyonunu önemli ölçüde olumsuz etkilemekte ve düşük altın kazanımlarına neden olmaktadır. Bu çalışmada, bakır içeren siyanür çözeltisinden altının seçimli olarak kazanılmasında farklı adsorbanların etkinlikleri araştırılmıştır. Aktif karbon (NORIT GAC 1240), karışık bazik (Purogold A193), kuvvetli bazik (Dowex 21K XLT, Purogold A194) ve zayıf bazik (Purogold S992) reçineler adsorban olarak test edilmiştir. Kavurma ön işlemine tabi tutulmuş yüksek bakır içerikli bir altın cevherinin siyanür liçi ile 28,2 mg/L Au ve 2804 mg/L Cu içeren yüklü liç çözeltisi elde edilmiştir. En yüksek adsorpsiyon kapasitesine aktif karbonun ve onu takiben de Purogold S992'nin sahip olduğu görülmüştür. Diğer taraftan, Purogold S992 (zayıf bazik) en düşük bakır adsorplama seviyesi ile altın için bakıra göre en yüksek seçimliliğe ulaşmıştır. Karışık ve kuvvetli bazik reçineler en yüksek bakır adsorpsiyonuna sahiptir. Elde edilen sonuçlar, Purogold S992'nin yüksek bakır içeren liç çözeltilerinden altının seçimli olarak kazanımında kullanılmasının uygun olduğunu göstermiştir.

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INTRODUCTION

Owing to the fact that cyanide forms strong complexes with gold, it is the most competent lixiviant for leaching of gold from ores (Senanayake, 2004; Breuer et al., 2005; Dai et al., 2010; Yang et al., 2010a,b; Bas et al., 2012 and 2015; Van Deventer, 2014). Cyanide is universally used due to its efficiency for gold and silver dissolution and fairly low cost without neglecting its selectivity for gold and silver over other metals (Senanayake, 2004; Marsden and House, 2006). Some copper minerals are also readily dissolved by cyanide to form copper cyanide complexes (Muir et al., 1989; Breuer et al., 2005; Yazici et al., 2015; Bas et al., 2015; Deveci et al., 2018; Msumange, 2019). Other metals like Zn, Fe, Co, Ni etc. can also be leached in cyanide media to a varying extent from their minerals present in the ore. Gold-cyanide complex can be recovered from pregnant leach solutions (PLSs) by either activated carbon or ion exchange resin (IX), more recently. The degree of adsorption depends on the nature of the adsorbent used and the chemistry of the solution to be processed (Marsden and House, 2006; Dai et al., 2010).

Activated carbon is widely used in many industrial applications in both liquid and gas separation processes, however, its employment in the industry of gold has only been prevalent since about 1980 (Marsden and House, 2006; de Andrade Lima, 2007; Sole et al., 2018). Properties like particle size, adsorption rate, reactivation characteristics, adsorptive capacity, mechanical strength and wear resistance are of paramount importance affecting the adsorption performance of gold onto activated carbon. Some physical factors may affect the adsorption process. These include carbon type and particle size, mixing efficiency and effects of solids. Practically carbons used in industrial applications typically vary from 1.2 x 2.4 mm to 1.7 x 3.4 mm. The rate of gold adsorption onto carbon can be directly affected by the presence of $Cu(CN)_2^-$ complex as it competes with gold adsorption (Marsden and House, 2006; Sayiner and Acarkan, 2014). Based on the previous findings present in the literature, during cyanidation process, many metal-cyanide species appear in the leaching process. Silver dissolves as $Ag(CN)_2^-$ complex and adsorbs on carbon better than other metal-cyanides apart from gold. As the concentration ratio of [Ag]:[Au] reaches 2:1, silver can be inhibitive for the gold adsorption on activated carbon (Adams, 1992).

Under laboratory conditions, the capacity of gold loading increases with the increase of cation concentration in solution in the following order of $Ca^{2+} > Mg^{2+} > H^+ > Li^+ > Na^+ > K^+$ and decreases with anion concentration in the order of $CN^- > S^{2-} > SCN^- > S_2O_3^{2-} > OH^- > Cl^- > NO_3^-$. The competitive adsorption of impurity metals with gold and silver for active carbon sites adversely affects the gold adsorption onto activated carbon. The adsorption rate of base metals onto activated carbon is less favoured compared to gold and silver. It follows the following trend: $Au(CN)_2^- > Hg(CN)_2 > Ag(CN)_2^- > Cu(CN)_3^{2-} > Zn(CN)_4^{2-} > Ni(CN)_4^{2-} >> Fe(CN)_6^{4-}$ (Marsden and House, 2006).

An alternative to activated carbon, which has received considerable attention over the years is ion exchange resins (Gomes et al., 2001; Leao et al., 2001; Bachiller et al., 2004). Commercially available resins have been unable to compete with activated carbon in most mineral systems because of poor selectivity, mechanical breakdown of beads and the requirement for complex elution and regeneration processes. However, resins offer some chemical advantages over activated carbon and have a high potential for application in gold recovery systems. The vital advantages of ion exchange resins encompass their low energy demand and superior selectivity for gold over base metals such as copper (Leao and Ciminelli, 2000; Van Deventer, 2011 and 2014, Van Deventer et al., 2012; Sole et al., 2018). Resins have potentially higher loading capacities/rates, are less likely to be poisoned by organics and do not require thermal regeneration (Van Deventer et al., 2012; Kotze et al., 2016; Sole et al., 2018). The main disadvantage of gold-selective resins is that they are more expensive than activated carbon (Marsden and House, 2006; Sole et al., 2018).

Gold selective resins that appear to be commercially viable are strong and weak/medium base anion exchange resins (Kotze et al., 2016). Generally, during adsorption, weak/medium base resins are more selective for gold over base metals and their elution is simply done by aqueous

NaOH (Van Deventer et al., 2012). They are also very sensitive to pH changes. The optimum pH range lies between 10 to 11 (Voiloshnikova et al., 2014a). Strong base resins have high metal loadings compared to weak/medium base ones without any dependency on pH. The selectivity of strong base resins is reduced due to the tendency of loading of base metals during the adsorption process. Elution of these resins is undertaken by the use of a mixture of thiourea and sulfuric acid, which has the possible source of danger for generating toxic HCN (Marsden and House, 2006; Van Deventer et al., 2012; Kotze et al., 2016). Figure 1 shows the relationship between pH and loading of gold onto different anion exchange resins as well as its elution from resins.

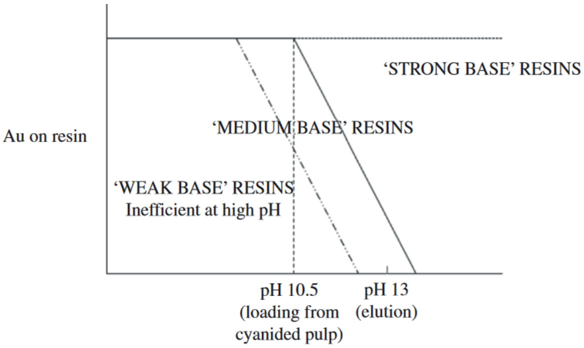

Figure 1. Effect of functional group basicity on the degree of protonation and loading of gold onto resin (Van Deventer, 2011)

When using a weak/medium-base resin, its functional group must be protonated so that the extraction takes place, since their functional groups are either secondary or tertiary amines, which have no permanent charge. Equations 1 and 2 show the mechanisms of protonation and adsorption, respectively:

$$P\text{-}NR_2 + H^+ \rightarrow P\text{-}NR_2H^+ \quad (1)$$

$$(P\text{-}NR_2H^+)_2SO_4^{2-} + 2Au(CN)_2^- \rightarrow 2P\text{-}NR_2H^+Au(CN)_2^- + SO_4^{2-} \quad (2)$$

If copper is present at high levels, the adsorption process is largely affected. When utilizing activated carbon, overall CN:Cu ratio should be decreased to 2, to achieve the most effective copper adsorption (Dai et al., 2010). The latter can be done by dissolving metallic copper into the leach solution. It is not necessary to decrease the CN:Cu ratio when using an ion exchange resin, this is because the $Cu(CN)_3^{2-}$ complex, which is the most dominant species in leach solutions can be stiffly adsorbed onto the resin (Marsden and House, 2006; Dai and Breuer, 2009; Dai et al., 2010). The adsorption of copper is strongly related to cyanide concentration and pH. At low pH and cyanide concentrations, formation of $Cu(CN)_2^-$ complex is favoured whilst the $Cu(CN)_4^{3-}$ complex predominates at high pH and cyanide concentrations. The adsorption of Cu-species decreases in the order: $Cu(CN)_2^- > Cu(CN)_3^{2-} > Cu(CN)_4^{3-}$ (Dai and Breuer, 2009; Van Deventer et al., 2012; Van Deventer, 2014). $Cu(CN)_2^-$ is the most problematic cyanide complex amongst others as it competes directly with $Au(CN)_2^-$ in the course of the adsorption process (Marsden and House, 2006; Van Deventer, 2014). When using activated carbon, to hinder the adsorption of copper, a molar ratio of CN:Cu should be kept at or above 4:1 in leach solutions (Muir, 2011).

In this study, the effectiveness of various adsorbents in the recovery of gold from cyanide leachate with a high level of copper concentration was investigated. Activated carbon (NORIT GAC 1240) and different kind of resins i.e., strong base (Purogold A194, Dowex 21K XLT), mixed base (Purogold A193) and weak base (Purogold S992), were employed. Gold selectivity over copper (Au/Cu), distribution ratio and the loading capacity of Au and Cu were examined.

1. EXPERIMENTAL

A copper-rich gold ore sample (108 g/t Au, 1.6% Cu, mainly composed of quartz and pyrite), which was used to produce real leach solutions was kindly provided by Koza Gold Co. (Gümüşhane/Mastra, Turkey). Table 1 shows the chemical analysis of the ore sample. The ore is classified as refractory due to its low response to direct cyanide leaching under the conditions of 1.5 g/L NaCN, 25% w/w solids ratio, 1.5 L/min air flow rate and pH 10.5-11 i.e., 18.4% Au extraction over 24 h. Roasting of the ore prior to cyanide leaching was proved to be an effective pretreatment route to achieve acceptable gold extractions from the ore (Msumange, 2019).

Table1. Chemical composition of the ore sample (Msumange et al., 2020)

Element/ Compound	Content (%)	Element	Content (g/t)
SiO_2	67.3	Au	107.7
Al_2O_3	11.51	Cu	15960
Fe_2O_3	6.06	Al	3900
MgO	0.45	Ni	604.5
CaO	0.46	Zn	926.1
Na_2O	0.06	Pb	838.1
K_2O	2.58	As	225
TiO_2	0.02	Ba	1211
P_2O_5	0.19	Ag	9.3
MnO	0.18	Sb	93.21
Cr_2O_3	0.015	Mo	24.64
Fe	4.02	Cd	10.7
S	3.46	La	1.64
K	0.21	Na	270
Ca	0.22	Mg	710
P	0.001>	Ti	23
LOI	6.03	Ga	5>
Total C	0.15	Bi	5>
Total S	4.56	Hg	5>
Sum	95.31	Be	1>

PLSs were prepared and used in the adsorption tests. They were derived from direct cyanide leaching (1.5 g/L NaCN, 25% w/w solids ratio, 1.5 L/min air flow rate, pH 10.5-11, 24 h) of the roasted ore (at 650 °C for 8 h). Gold and copper concentrations in PLSs were determined to be 28.2 mg/L Au and 2804 mg/L Cu, respectively. The PLSs were prepared in 50-mL Erlenmeyer flasks, which were then placed onto an orbital shaker (Wiggen Hauser). Prior to the addition of adsorbents, air (1.5 L/min) was supplied into the flasks with PLSs. pH was maintained at 10.5-11 by the use of 1 M NaOH, if required.

Adsorption tests were conducted to compare the effectiveness of various adsorbents for gold recovery from cyanide leachate having a high level of copper. By the use of activated carbon (NORIT GAC 1240), mixed base (Purogold A193), strong base (Dowex 21K XLT, Purogold A194) and weak base (Purogold S992) resins, gold selectivity over copper and the loading capacity were evaluated. The distribution ratio of Au and Cu was also determined. The activated carbon (NORIT GAC 1240) had an effective size of 0.65 mm (NORIT, 2003). The technical features of the resins used in this study were presented in Table 2. When the pH of PLSs was around 10.5-11, the adsorbent used was introduced into Erlenmeyer flasks. Only Purogold S992 was tested at pH 10-10.5 due to its high pH sensitivity. To avoid evaporation of the leach solution, the mouth of the employed conical flasks was covered by a sponge. Adsorption tests were carried out using the adsorbents (5 g/L) under the conditions of 25 °C at 170 rpm stirring speed over a period of 24 hours. Sampling was carried out at predetermined intervals by removing 1 mL solution from each flask. At the end of the tests, solutions were diluted with 1.5 g/L NaCN and metal concentrations were analyzed by atomic absorption spectroscopy (AAS, Perkin Elmer AAnalyst 400).

The employed weak base resin (Purogold S992) was firstly transformed into the form of sulfate before the tests to interact with metal-cyanide anions. As indicated previously, protonation of this type of resin is a prerequisite for the extraction process to occur. They were contacted with two-bed volumes (BV's) of a 0.5 M $Na_2SO_4.10H_2O$ solution in a column. The rate of flow was 2-bed volume per hour (volume of resin used is defined as a BV). 4 BV's of water was utilised to cleanse the excess reagent from the resin (Van Deventer et al., 2014). It should be noted that the weak base resin (Purogold S992) is very sensitive to pH, and performs best in the pH range between 10 and 11. Van Deventer et al. (2012) reported that optimum Au loading and minimum Cu co-loading on Purogold S992 occurred at pH 10.4-10.5. Voiloshnikova et al. (2014a) investigated the performance of gold adsorption on Purogold S992 from synthetic gold and multi-metal cyanide solutions. Equilibrium tests showed that the resin was sensitive to pH in that gold loading decreased from 23,700 g/ton to 2,380 g/ton by increasing the pH from 10 to 11 from the solution containing 1 mg/L Au. No gold adsorption took place at ≥pH 12.5. Relying on these facts, in the current study the pH was maintained between 10-10.5 in the tests where Purogold S992 was used.

The selectivity, μ, and adsorbent loading capacity, A (mg/g), were calculated using Equations 3 and 4 respectively.

$$\mu = \frac{D_{Au}}{D_{Cu}} = \frac{[Au]_{adsorbent} x [Cu]_{solution}}{[Au]_{solution} x [Cu]_{adsorbent}} \quad (3)$$

$$A = (C_o - C_f) \times V \times m^{-1} \quad (4)$$

where, D_{Au} and D_{Cu} are distribution ratios for Au and Cu, respectively. C_o is the initial concentration of adsorbate in solution (mg/L), C_f is the equilibrium concentration of adsorbate in solution (mg/L), V is the volume of solution (L) and m is the adsorbent mass (g).

Table 2. Technical features of the ion exchange resins used in the tests (Van Deventer et al., 2012 and 2014; PUROLITE, 2015, 2016a,b, 2020; URL, 2020)

Name/brand of the resin	Matrix / Type	Functional Group	Ionic Form	Capacity	Moisture retention (%)	Effective size (µm)
Dowex 21K XLT	Styrene-divinylbenzene / Type I Strong base anion	Quaternary Amines	Cl^-	1.4 eq/L	50-60	525-625
Purogold A193 *	Macroporous polystyrene-divinylbenzene / Mixed base anion	Mixed Tertiary & Quaternary Amines	Cl^-	3.8 eq/kg	46-56	800-1300
Purogold A194 *	Macroporous / Strong base anion	Quaternary Amines	Cl^-	3 eq/kg	44-52	710-1300
Purogold S992 *	Macroporous polystyrene-divinylbenzene / Weak base, Chelating	Mixed Amines	FB	4.4 eq/kg	47-55	800-1300

* Developed for adsorption of gold-cyanide complexes from cyanide liquors, FB = Free Base

2. RESULTS AND DISCUSSION

The pregnant leach solution used contained 28.2 mg/L of gold and 2804 mg/L of copper. The pH-dependent distribution of Cu(I)-cyanide species in PLS used was determined by MEDUSA (2009) software (Figure 2). This speciation plot pointed out that the dominant Cu(I)-cyanide species in the solution during the adsorption tests were $Cu(CN)_3^{2-}$ with ≈65% followed by $Cu(CN)_4^{3-}$ with ≈35% over the pH range of 10-11.

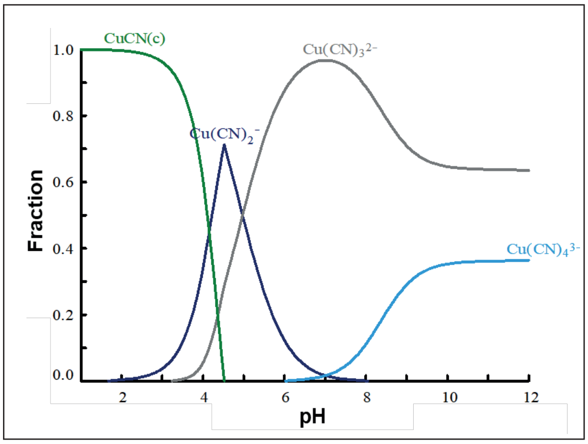

Figure 2. Speciation of Cu(I)-cyanide species *vs.* pH reflecting the conditions of PLS produced (CN_{Total}=0.153 M, Cu(I)=2804 mg/L, Au(I)=28.24 mg/L) (MEDUSA, 2009)

Kinetics of gold and copper loading onto adsorbents (mass of metal per tonne of adsorbent) and the change in the solution metal concentrations at pH 10.5-11 or 10-10.5 (for Purogold S992) are presented in Figures 3-7.

Considering the gold loading capacity, it is seen that activated carbon loaded more gold than other adsorbents tested. Around 2856 g of Au were loaded per ton of activated carbon within just the first 2 hours. This is above half of the total gold loaded over a period of 24 hours (Figure 3). Dowex 21K XLT resin showed the lowest performance in gold adsorption in that gold loading reached its maximum (1978 g/ton) in 2 hours (Figure 4).

During the first hour of adsorption, gold loading on the activated carbon was 2347 g/t (Figure 3) while those for Purogold A193 and Purogold A194 were 1286 g/ton and 1786 g/ton, respectively (Figures 5-6).

The difference between gold loading values of activated carbon and Purogold A193 within the first hour of adsorption was 1061 g/ton. Over the same period of 1 hour, 1786 g/ton that is 53% of the total loaded gold onto Purogold S992 was observed (Figure 7). These data could simply indicate the superior gold loading capacity of activated carbon compared with Purogold S992, Purogold A194, Purogold A193 and Dowex 21K XLT, respectively, in descending order of gold loading.

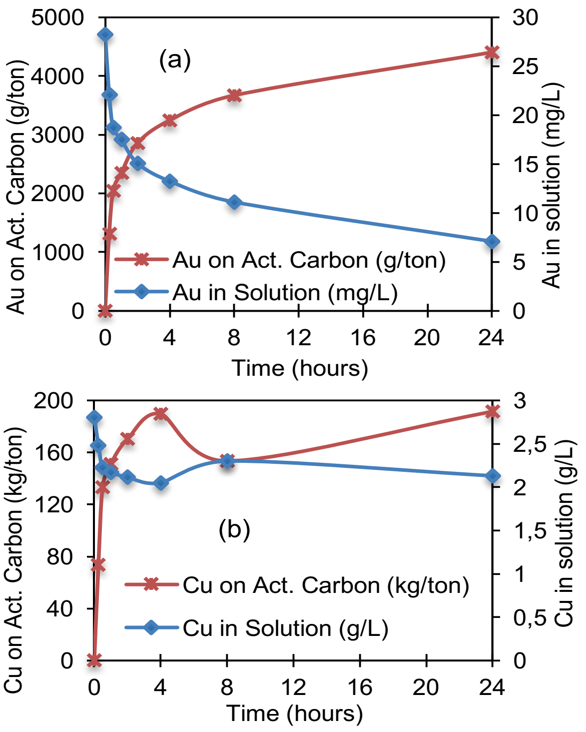

Figure 3. Kinetics of gold (a) and copper (b) loading onto activated carbon and metal concentrations (pH 10.5-11)

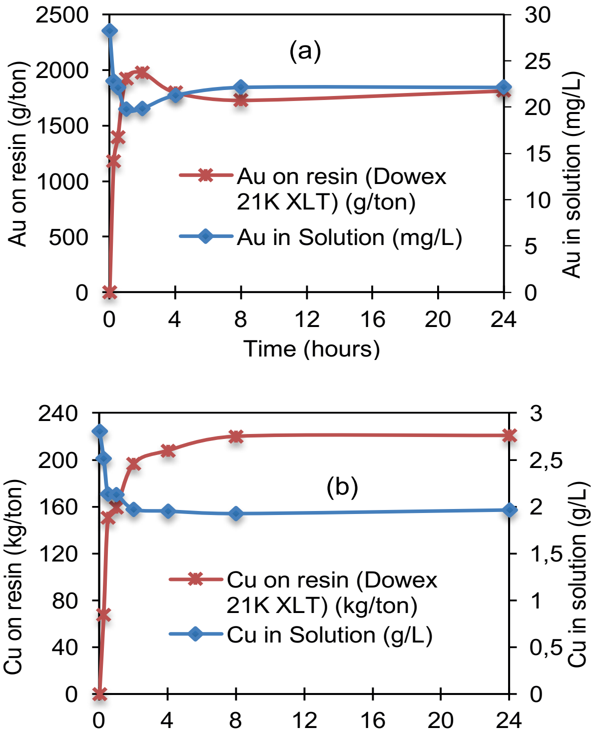

Figure 4. Kinetics of gold (a) and copper (b) loading onto Dowex 21K XLT resin and metal concentrations (pH 10.5-11)

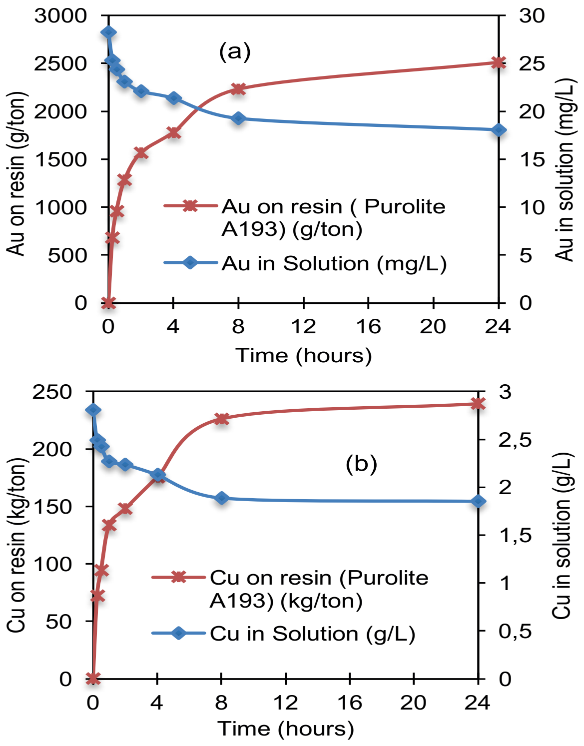

Figure 5. Kinetics of gold (a) and copper (b) loading onto Purogold A193 and metal concentrations (pH 10.5-11)

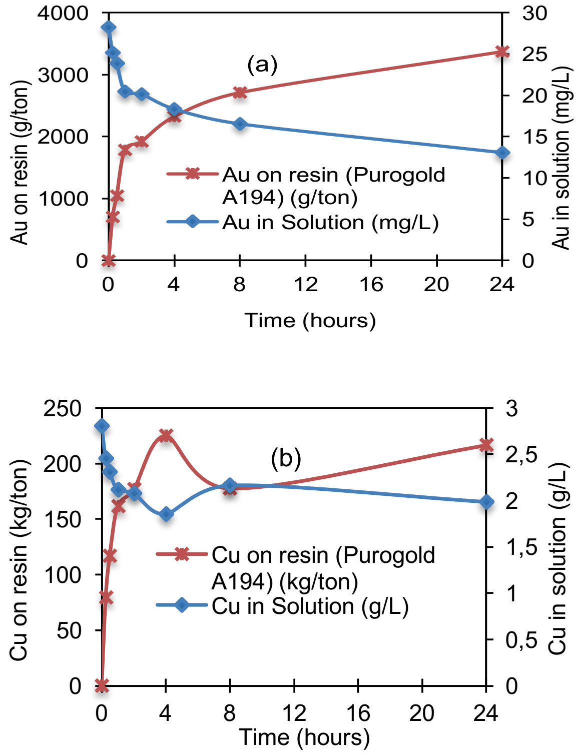

Figure 6. Kinetics of gold (a) and copper (b) loading onto Purogold A194 and metal concentrations (pH 10.5-11)

Comparative gold and copper adsorption percentages over 24 hours were demonstrated in Figure 8. Distribution ratios of gold and copper, selectivity coefficient (μ) and amount of metal(s) loaded on adsorbent (kg/ton or g/ton) were also calculated (Table 3). The selectivity of an adsorbent is defined as its gold loading relative to copper loading and formulated as the ratio of the distribution of gold to that of copper (Equation 3).

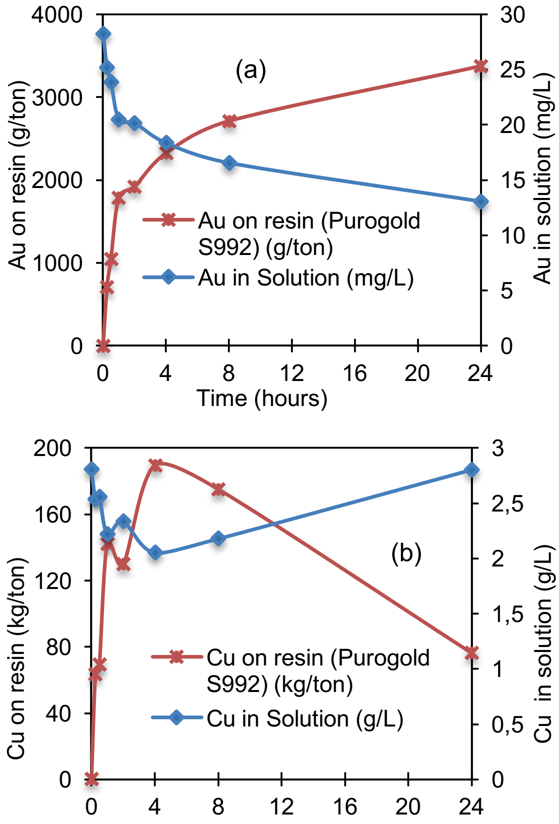

Figure 7. Kinetics of gold (a) and copper (b) loading onto Purogold S992 and metal concentrations (pH 10-10.5)

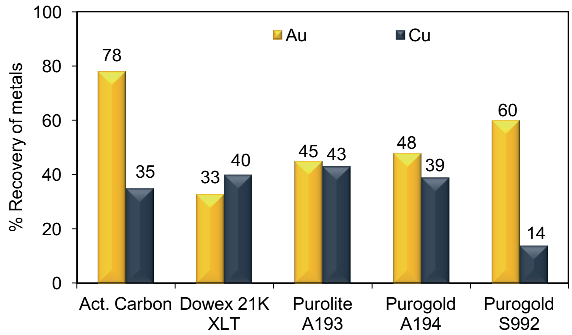

Figure 8. Percentage of metals recovered by adsorbents

Activated carbon was apparently found to have the highest gold loading capacity (4406 g/ton) and hence distribution ratio (620) compared to other adsorbents used (Table 3). Purogold S992 was the second adsorbent to recover gold in greater amount. Despite the fact that the amount of gold loaded onto activated carbon was high, yet it was not as selective as Purogold S992 which had the superior selectivity for gold with its characteristic of having the lowest copper loading. The latter loaded only 76 kg/ton of copper over a period of 24 hours (14% of Cu in the PLS was adsorbed), while 192 kg/ton were loaded onto activated carbon over the same period. In fact, Purogold S992 loaded the lowest level of copper amongst the adsorbents tested (Table 3). The utilisation of the Purogold S992 with its high selectivity for gold over copper will not need extra inventory for the loading of copper and hence, the productivity will be higher.

Consistently, Van Deventer et al. (2012) previously demonstrated that no copper was loaded onto Purogold S992 from a synthetic gold

Table 3. Comparison of the activated carbon with IX resins used for the adsorption of Au and Cu from a real cyanide leach solution (28.2 mg/L Au, 2804 mg/L Cu, Conc of Adsorbent: 5 g/L, pH 10.5-11, 25 °C, 24 h)

Adsorbent	D (Au)	D (Cu)	μ (Selectivity)	Au on Adsorbent (g/ton)	Cu on Adsorbent (kg/ton)
Activated Carbon	620	90	6.9	4406	192
Dowex 21K XLT	82	112	0.7	1814	221
Purogold A193	139	129	1.1	2510	239
Purogold A194	158	109	1.5	2688	216
Purogold S992 *	258	27	9.6	3373	76

* pH was controlled at 10-10.5 in the tests where Purogold S992 was used.

leach liquor (9 mg/L Au, 13.6 mg/L Cu, 1.0 mg/L Zn, 10.4 mg/L Ni) with a selectivity order of Au > Zn > Ni >> Cu. They also noted that activated carbon loaded 3.9-fold higher gold compared to Purogold S992 (i.e., 16,450 *vs.* 4183 g/ton) at the expense of higher copper and zinc loadings compared to the resin.

Mixed base (Purogold A193) and strong base resins (Purogold A194) appear to have relatively a high gold loading capacity, but, poor selectivity due to comparatively high loadings of copper (239 kg/ton and 216 kg/ton, respectively). Purogold A193 appeared to show the highest adsorption for copper followed by Dowex 21K XLT, a variation of 3% in terms of Cu recovery for Purogold A193 and Dowex 21K XLT was observed (Figure 8). However, the difference in Cu recoveries for Dowex 21K XLT and Purogold A194 was just by 1%. Amongst the adsorbents, Dowex 21K XLT seems to be the most non-selective adsorbent as the amount of copper recovery was higher by 7% to that of gold (Figure 8) as an indication of its non-selective character.

These findings showed that base metals such as Cu could be favoured during adsorption onto strong base resins. Gold loadings and selectivities (μ) for Purogold S992 (and other resins) were observed to be strongly affected by the presence of an excessively high concentration of copper (i.e., 2804 mg/L Cu) as well as ionic strength in the PLSs which may result in the competition of other anions and copper/metal-cyanide complexes with gold-cyanide complexes. Possible presence of dissolved silica in the PLSs may also contribute to the fouling of the resin and hence reduction in the gold loading (Marsden and House, 2006; Sayiner and Acarkan, 2014; Van Deventer, 2014).

Consistent with the current findings, previous studies (Fleming and Cromberge, 1984; Marsden and House, 2006; Van Deventer et al., 2012) highlighted that weak and medium base resins possess higher selectivity for gold over copper than strong base resins when used in cyanide leach solutions. Many investigators (Van Deventer et al., 2012; Van Deventer, 2014) reported that weak base resin (Purogold S992) has high selectivity for gold over copper from cyanide liquors. Voiloshnikova et al. (2014a) reported that the selectivity of the Purogold S992 is in the order of $Au(CN)_2^- > Zn(CN)_4^{2-} > Ag(CN)_2^- > Fe(CN)_6^{3-} > Cu(CN)_3^{2-}$. Van Deventer et al. (2014) compared the performance of Purogold S992, Purogold A194 and activated carbon using a synthetic solution containing 1.4 mg/L Au and ~1 g/L Cu. They reported a selectivity (Au/Cu) order of the adsorbents as Carbon>S992>A194. The loading of gold by the adsorbents followed an order of A194>Carbon>S992. The difference of these results (Van Deventer et al., 2014) with the current findings (Table 3) can be attributed to the type of activated carbon used, solution chemistry and interference of other ions in the real PLSs as used in the current study. Voiloshnikova et al. (2014b) applied continuous resin-in-pulp (RIP) tests to a gold ore containing 2 g/ton Au, using Purogold S992 as the resin. They obtained a final gold recovery of 94.3%. The authors also noted that the gold loaded onto the resin could be easily eluted using a concentrated cyanide solution (20 g/L NaCN; 5 g/L NaOH, 60 °C) with an average gold stripping recovery of 97%.

A previous report by Ahlatcı et al. (2018) also supported the low copper loadings of Purogold S992 observed in the current study (Table 3). Ahlatcı et al. (2018) tested the adsorption performance of Cu, Zn and Fe from waste cyanide solutions (after gold recovery; 135 mg/L Cu, 196 mg/L Zn, 5.3 mg/L Fe, 1.5 g/L NaCN, pH 10.5) using Dowex 21K XLT, Purogold A193 and Purogold S992 resins. They found that Dowex 21K XLT resin loaded the highest amount of copper (10.2%) and zinc (24.5%) over 24 hours, while other resins showed no or limited adsorption (i.e., ≤3%) of Cu/Zn.

CONCLUSION

The gold loading capacity and selectivity of various adsorbents (activated carbon, Dowex 21K XLT, Purogold A193, Purogold A194, Purogold S992) were evaluated from a cyanide leachate containing 28.2 mg/L Au and 2804 mg/L Cu. The experimental findings indicated that the activated carbon has the highest gold loading capacity among the adsorbents tested. However, the selectivity of the activated carbon was remarkably lower than Purogold S992. The latter adsorbent was found to have the highest selectivity. Other resins tested appeared to have even lower selectivity than activated carbon. The order of selectivity obtained was as follows: Purogold S992 > Activated carbon > Purogold A194 > Purogold A193 > Dowex 21K XLT. The difference in selectivities between the employed adsorbents could be related to the amount of copper present in the solution(s) and the chemistry of the respective adsorbent. Considerably high copper levels in the PLS used could have directly interfered with the adsorption process due to the direct competition of copper cyanide complexes with gold cyanide complex to the active sites. These findings suggest that Purogold S992 could be suitably used for the recovery of gold from cyanide leach solutions laden with copper relying on its relatively high capacity coupled with superior selectivity for gold over copper.

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