

Characterization and recovery of gold associated with fine, activated carbon

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The attrition of activated carbon, and the loss of gold associated with it, is of significant economic importance to the operation of a CIP/CIL circuit

The focus of this study was on activated carbon recovered from an elution circuit which was deemed too fine for reuse. Results of cyclosizer and laser particle size analysis identified that most of the carbon was contained in the larger size fraction suggesting formation by abrasion. Digestion and AAS analysis of the individual size fractions identified a disproportionate concentration of gold in the finer size fractions which was identified by scanning electron microscopy to be due to the presence of fine metallic gold formed as a result of the acid washing process.

Attempts to strip the remaining gold using sodium hydroxide or sodium sulphide based solutions proved unsuccessful due to poor elution efficiencies and re adsorption of gold. Upgrading of the material by froth flotation was also investigated using various conventional flotation reagents which had some success in concentrating the free metallic gold, however, grade and/or recoveries were considered less than desirable.

Greater success was ultimately found in the transfer of gold from the fine carbon material onto coarser virgin activated carbon using a caustic cyanide solution. Sodium sulphide, sodium chloride and ammonium chloride based solutions were also trialled but proved less successful owing to their inability to mobilise metallic gold or gold cyanide species. Repetition of the transfer process proved capable of stripping 97% of the gold contained on the carbon fines for a bed volume ratio of 6:1.

Introduction

Due to the potential losses of gold associated with fine carbon, most precious metal producing companies employ some method to recover at least part of the residual carbon fines (Hill and Lin 2001). This residual carbon, however, is usually processed off site by another company, the carbon fines generated by Stawell Gold Mines being used, for example, as fuel for a copper smelter, the contained gold and silver being recovered from the copper produced (P. Wemyss, Personal Correspondence 2001).

A number of methods for the recovery of gold from waste activated carbon have been investigated including one described by Amankwah and Asiam (1996), in which the waste carbon is finely ground then heated in air to oxidize the carbonaceous components. Gold is then recovered from the oxidized carbon by a conventional cyanide leach. There are, however, significant problems associated with such a method namely the high costs associated with processing the waste carbon material along with the environmental aspect of carbon dioxide emission.

Consequently, a need exists for a means of processing waste activated carbon at Stawell Gold Mines which can profitably recover the 150 to 200 grams of gold per ton of waste carbon whilst minimising carbon dioxide emissions. An ideal process would allow the gold to be recovered on site, however, there is also merit in a process which could reduce the cost of transport and/or processing by increasing the gold grade of the material.

Materials

The fine carbon material forming the basis of this research was collected as a number of 1L samples from eluted carbon deemed too fine for re use which had been separated by screening. Samples were blended, dried at 110°C then sealed until required. Average gold assay for this material was 157 ppm.

Laboratory Equipment and Technique

Size analysis was conducted using wet screening, to minimize dust, down to 45 microns. A Warman cyclosizer was used for the sub 45 micron size fraction. Analysis of the cyclosizer discharge was conducted using a Malvern Instruments Master Sizer Hydro 2000 laser particle sizer with pure carbon being chosen as the reference material.

Batch elution experiments were conducted in stirred 2 L conical flasks heated to 60°C. All sodium sulphide based eluants contained 0.1M of Na₂S along with 0.1M of NaOH to control pH and minimise the formation of sulphur dioxide. Additional eluants were made up through the addition of 1 M NH₄CL, 5M Na₂S₂O₃, 0.1M NaCO₃, 50g/L NaCl or 0.1 M K₂S to the base sodium sulphide solution. It should be noted that due to a lack of K₂S a laboratory grade solution of sulphurated potash was substituted (a mixture of >98% K₂S with K₂S_x, K₂O₃S₂ and K₂SO₄ impurities).

The initial sodium sulphide elution trial was conducted using 20 g of carbon and 2 L of solution, the ammonium

chloride elution involved 50 g of carbon and 2 L of solution with remaining experiments being conducted using 25 g of carbon and 1 L of solution. 50 ml samples were taken periodically, from the elution trials with the volume of liquid removed being replaced by fresh eluant solution. Sodium hydroxide elution trials were conducted in a similar manner with the elution of a 20 g sample of carbon with 2 L of 0.1 M NaOH solution.

All flotation experiments were conducted in a 2L-perspex vessel using an Agitair La-500 flotation cell. Experiments were conducted using 225 g of blended fine carbon sample and 1.5 litres of mains, potable water. A conditioning time of 10 minutes was used for the first experiment; however, a reduction to 5 minutes on the subsequent experiment showed no significant effect on recovery and so this time was used for all further experiments.

In all instances, froth was collected from the surface of the flotation cell for no more than 5 minutes to reduce entrainment. Both the flotation concentrate and tailings were dried at 110°C and weighed, the tailing sample providing the feed for the next stage of flotation. Reagent levels and flotation conditions for each flotation experiment are summarised in the following tables.

All experiments concerning the transfer of gold to virgin activated carbon were conducted using covered, stirred, 600 ml flasks heated to 60°C containing 5 g of sample and 500 ml of solution. Sodium cyanide solutions of 0.001, 0.01 and

0.1 M concentration were prepared with 0.1 M of sodium hydroxide added to each to prevent cyanide loss. The virgin carbon used for these experiments was a Calgon coconut shell derived activated carbon, which was untreated prior to the experiment. Unless otherwise stated, all experiments had a 2:1 ratio by weight of virgin carbon to sample. For the final experiment the virgin carbon was removed by screening every 2 hours and replaced by an equivalent mass of virgin carbon.

All necessary gold assays of dry solids were determined using di isobutyl ketone (DIBK) solvent extraction and atomic absorption spectrometry. Determinations of levels of gold in solution were conducted using direct AAS analysis. Carbon contents were approximated by measuring the mass loss after heating the sample to 850°C for 2 hours.

Distribution of gold in carbon fines

The analysis of the separated, size fractions of the feed material given in Figure 1 reveals a greater concentration of gold in the sub 45 micron fraction than would be expected if it were present only as an adsorbed cyanide species. Scanning electron microscopy confirmed fine particles of metallic gold in all size fractions, but were most prevalent in the sub 45 micron size fraction (see Figure 2). Composition of the gold particles was found to vary.

Table I
Conditions for first flotation experiment

RPM = 700 Airflow = 4 SLPM pH = 10.2	
Gold flotation	Carbon flotation
2.2g/kg PAX	2.3 ml/L kerosene
20.67g/kg Aerofloat 208	Frother addition
Frother addition	Stage 1 = 2 drops pine oil
Stage 1 = 2 drops pine oil	Stage 2 = No frother addition
Stage 2 = 3 drops pine oil	Stage 3 = 3 drops MIBC
Stage 3 = No frother addition	

Table II
Conditions for the second flotation experiment

RPM = 600 Airflow = 4 SLPM pH = 9.9	
Gold flotation	Carbon flotation
0.33g/kg PAX	Stage 1 = 5.8ml/L kerosene
3.1g/kg Aerofloat 208	2 drops MIBC
Frother addition	Stage 2 = 11.6ml/L kerosene
Stage 1 = 3 drops pine oil	No frother addition
Stage 2 = 3 drops pine oil	Stage 3 = 11.6ml/L kerosene
Stage 3 = No frother addition	2 drops MIBC

Table III
Conditions for the third flotation experiment

RPM = 600 Airflow = 4 SLPM pH = 9.4	
Carbon flotation	Gold flotation
Stage 1 = 2.9ml/L kerosene	0.3kg/kg PAX
3 drops MIBC	3.1g/kg aerofloat 208
Stage 2 = 5.8ml/L kerosene	Frother addition
2 drops MIBC	Stage 1 = 3 drops pine oil
Stage 3 = 11.6ml/L kerosene	Stage 2 = 3 drops pine oil
2 drops MIBC	
Stage 4 = 5.8ml/L kerosene	
2 drops MIBC	

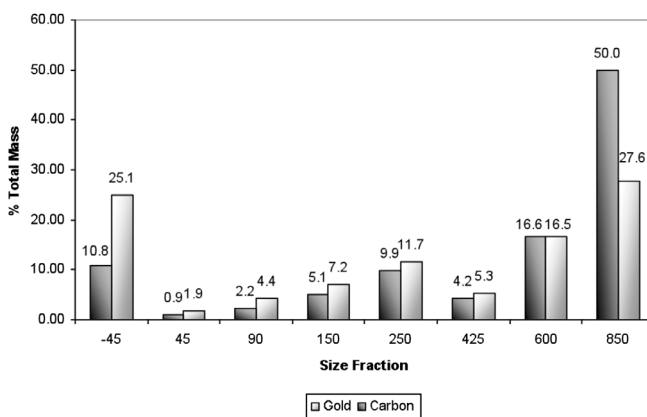


Figure 1. Distribution of gold and carbon by size

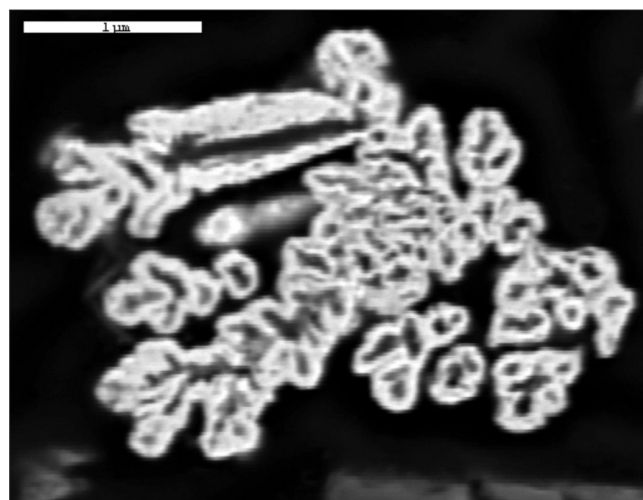


Figure 2. Backscattered electron image of metallic gold in -45 micron size fraction

Particles containing low concentrations of silver equivalent to those found in the ore were present. However, particles of electrum, virtually pure gold and pure silver were also found which are not present in the ore. The presence of these particles is attributed to reduction of adsorbed species during the acid washing stage of the elution process, which was confirmed by SEM analysis of washed and unwashed loaded carbon samples. Average gold grade for the feed material was found to be 157 ppm.

Elution of carbon fines

Since the carbon material received had already undergone conventional cyanide based Zadra elution, any attempt to strip the carbon further using cyanide was not considered likely to result in high gold recoveries under atmospheric conditions. Instead, other solutions, noted for their ability to mobilise gold (Pyke *et al.* 1997), were trialled with the intent of developing a process that would not require the expense associated with elevated temperatures and pressures, or high reagent concentrations. As can be seen in Figure 3, no success was found with these particular reagents. However, research into alternative reagents is ongoing.

The apparent increase in gold concentration seen with some samples, is believed to be due, simply, to the dissolution of some of the gangue material associated with the fine carbon material. No significant concentration of gold was detected in any of the solution samples taken, with most recording values below 5 ppm.

Separation by froth flotation

Given the difficulties in treating a material containing gold in both adsorbed and free metallic forms, the use of flotation was investigated as a means of separating the metallic and adsorbed gold. As can be seen in Figure 4, attempts to produce a metallic gold concentrate first failed to produce a significant improvement in the gold grade. By reversing the order and pre floating the carbon in the third experiment success was achieved in producing a higher grade concentrate, but at the expense of overall recovery. Subsequent experimentation failed to produce higher gold grades or recoveries. Although these concentrates could conceivably be smelted directly, the use of flotation still leaves the adsorbed species requiring treatment. The idea that these could also be reduced to a metallic state with acid and flotation repeated was considered, but not explored, as it seemed unlikely that such a process could be made economically viable.

Transfer of gold from fines to virgin activated carbon

Based on the work of Hill and Lin (2001), the idea that adsorbed gold could be transferred unto unloaded, virgin carbon was explored with a view to finding a means by which the process could be optimized. From the results of the single batch trials (see Figure 5), altering the mass of the virgin carbon used appears to have had little effect on the efficiency of the process. A far greater difference was found with increasing the concentration of the solution, or increasing the residence time from one hour to two. The possibility that the kinetics could be improved by altering the temperature was considered but not investigated since cost of the process was considered a greater priority than speed.

Further experimentation instead focused on the effect of replacing the virgin carbon in solution as a means of

improving kinetics and increasing gold removal. From the results seen in Figure 6, it can be seen that after just 3 cycles 97% of the gold contained in the carbon fines had been recovered using a sodium cyanide based solution. Non cyanide solutions were also trialled, but ultimately proved far less successful, this being attributed to their inability to mobilise the metallic gold present in the sample. Furthermore, although the gold adsorbed by the virgin

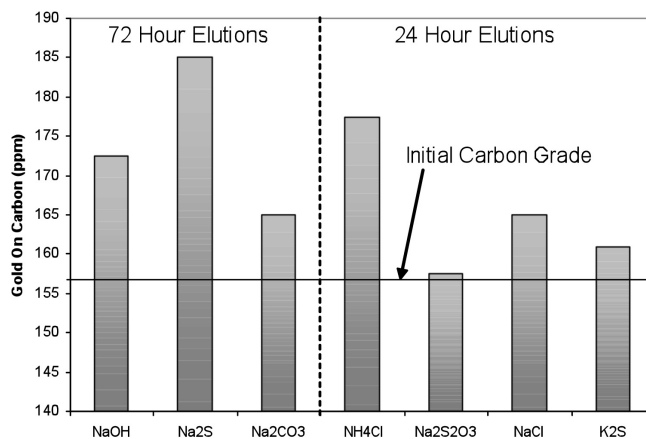


Figure 3. Gold loadings of eluted carbon

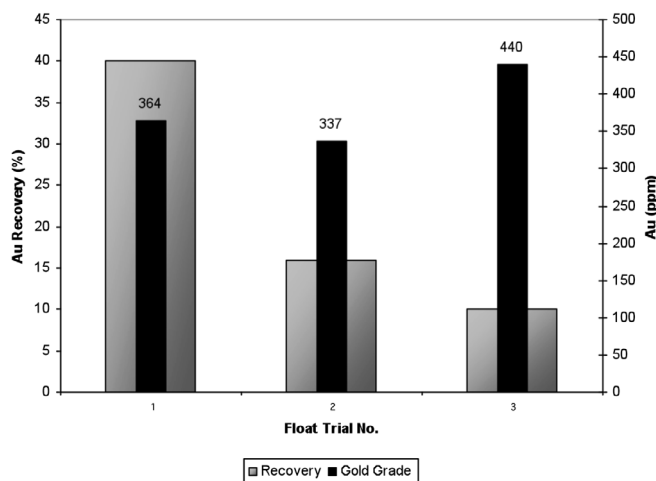


Figure 4. Grade recovery of flotation concentrates

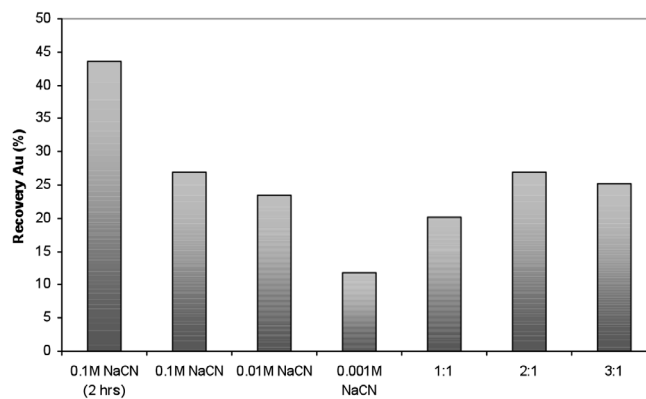


Figure 5. Effect of carbon volume and cyanide concentration on total gold recovery

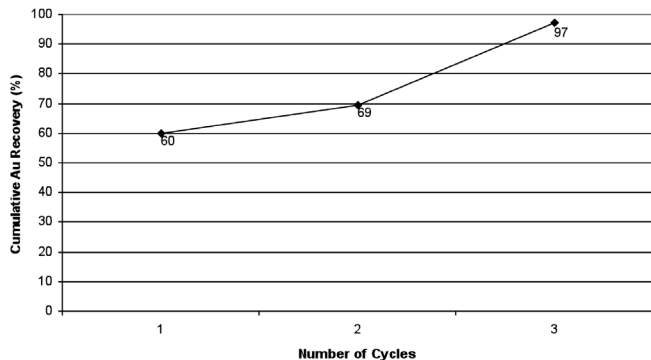


Figure 6. Cumulative gold recovery from multiple transfer cycles

carbon could be indirectly recovered by adding it to a conventional CIP/CIL circuit, there exists the problem of the quantity of carbon required, and the risk of reducing the efficiency of the plant.

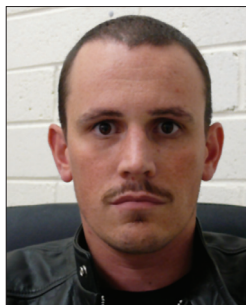
Conclusion

It is the presence of both adsorbed and metallic gold in eluted carbon that creates the biggest problem in the recovery of gold from carbon fines. Separation of the material by flotation was found possible but this is unlikely to provide a solution for cheap, on site processing unless

high losses are considered acceptable. Transferral of the gold to virgin, activated carbon proved more promising but is ultimately limited by the fact that it has the same affinity for gold as the sample material and a large quantity of virgin carbon is, therefore, required. One aspect which was not investigated as part of this research was the possibility that the transfer of gold may be improved by utilising a material, such as an ion exchange resin, which has a greater affinity for gold under certain conditions. Whether a relatively small quantity of material can achieve gold loadings, considerably, in excess of the waste carbon being treated is something which may well be worth exploring.

References

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Completing an honours degree in metallurgy at the University of Ballarat in 2001 I spent 2 years working as a research and product development scientist in the food industry before returning to the University of Ballarat to commence a Doctorate of Philosophy in Metallurgy. During this time I found part time employment in the metallurgical laboratory of Gekko systems and as a consultant metallurgist during the commissioning of the BIOX circuit at Fosterville. I have been employed as a lecturer in mineral processing at the University of Ballarat for the last 2 years.