RECENT ADVANCES IN THE EXTRACTION, PROCESSING AND APPLICATION TECHNOLOGIES OF GOLD

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ABSTRACT

The largest and most important development in the recovery of gold was the introduction of the carbon-in-pulp process. Whilst fundamental and modelling studies have contributed significantly towards understanding and optimizing gold processing, the greatest improvements over the last 20 years have come in the area of process engineering. This paper discusses amongst other, developments in the field of bioprocessing of refractory ores, alternative lixivants for cyanide, resin-in-pulp technology and industrial applications for gold.

INTRODUCTION

Towards the end of 1998, the price of gold sank to its lowest level for 18 years, due partly to increases in world mine production and scrap supply, and particularly to the selling and lending of gold by the central banks. There is thus a dual pressure on gold producers – to lower costs and to keep growing.

Gold is an extremely precious metal that has been discovered in varying amounts in most areas of the globe. In the earliest discoveries gold was found in nugget formation and was recovered by hand-picking. Then, with the discovery of alluvial deposits, concentration by gravity means followed. Amalgamation by mercury then found ready application, either as a replacement for or as an adjunct to gravity concentration. Eventually, dissolution by cyanide in conjunction with precipitation by zinc emerged as the outstanding hydrometallurgical technique for gold recovery (Adamson, 1972).

The largest and most important development in the recovery of gold by carbon-in-pulp (CIP) was the introduction in 1973 of the process at the Homestake Mine in South Dakota (Hall, 1974). This carbon-in-pulp plant, which has been operating in a highly successful manner since its inception, has changed the image of the carbon-in-pulp process from an experimental small-scale process into a viable established process that can be used for the treatment of high-tonnage flows. While the research on the mechanism and kinetics of adsorption, elution, acid washing and the thermal regeneration of spent carbon have added greatly to the understanding of the process, this knowledge has lagged behind practical innovations. Hence, the greatest improvements to the CIP process over the last 20 years have come in the area of process engineering.

The use of alternative sorbents to carbon which have higher loading capacities, greater selectivity for gold cyanide and the ability to enhance the extraction of gold from refractory and pregrobbing ores is sought. The world’s first commercial application of the resin-in-pulp (RIP) process for precious metal recovery occurred in the Soviet Union (Fleming, 1982). Resins are more versatile substrates than activated carbon because specific functional groups can be introduced onto the resin matrix during synthesis to alter their sorptive properties. In addition, it has been demonstrated that resins in comparison to carbon have superior kinetics and greater equilibrium loading capacity of gold cyanide (Fleming and Cromberge, 1984). It has also been proposed that ion exchange resins have the potential to minimise the effects of re-adsorption of gold onto the ore (pregrobbing) during the leaching and adsorption stages (Van den Berg and Petersen, 2000).

More often than not, gold is locked into the crystal structure of the sulphide mineral and is difficult to extract by cyanidation, thus the term refractory. Bacterial oxidation, which operates at near atmospheric conditions with a temperature of 40 – 45 °C and a pH of 1.5, comprises a dual mechanism both indirect via the ferrous/ferric couple and so called direct attack whereby the bacteria attach to the sulphide surface and facilitate electron transfer. It is probably this direct attack which leads to improved selectivity. The first commercial bacterial oxidation plant started up in October 1986, using the BLOX technology. Subsequently, various other have been brought into production, and recently the Mintek/BacTech bacterial oxidation process has
been implemented at the Beaconsfield gold mine in Tasmania.

A solvent-extraction route developed at Mintek, South Africa for the chemical refining of gold from chloride media has shown considerable promise for the selective recovery of gold from silver, platinum-group metals (PGM's) and base metals, and has potential applications in the refining of gold from various feed materials. This process is able to produce 99.9 percent gold from a variety of concentrates and other materials, and is aimed specifically at the small-to medium-scale mining sector. In particular, this process allows almost total gold recovery from the gravity concentrates, and eliminates the need for slag recycle to the mill, with consequent gold lock-up and loss that results from smelting the concentrates (Feather, et al., 1997).

Cyanide has been the principal reagent used in the processing of gold during the last century. Producers and researchers began to consider seriously the toxicity of cyanide to biological systems during the latter decades. Consequently, efforts were started to find an alternative reagent. Although various lixiviants such as thiourea, thiosulphate, halogens and ammonia have been investigated, none of these has been implemented on a large scale commercial plant as yet. On the other hand, the Australian Mineral Industries Research Association (AMIRA) managed a detailed programme related to cyanide. Aspects such as speciation, the nature, behaviour and transport of cyanide in and around the tailings environment, as well as a common laboratory procedure for sample analysis were exclusively researched. The Cynoprobe, an online cyanide-measuring (free cyanide plus loosely associated cyanide) instrument based on amperometric detection was also developed.

In a world of global capital markets where, increasingly, shareholders have unlimited options with regard to investment, gold must compete with all other categories of investment. Anglogold, the world largest gold producer with an annual production of over 7.5 million ounces, and Mintek have recently gave life to project AuTEK to investigate the industrial applications for gold. It draws strengths from the fact that gold has unique properties that can be utilized optimally and profitably in applications over and above jewellery production, especially in environmentally sensitive areas.

This paper presents some advances in the extraction and application technologies of gold.

**CARBON-IN-PULP**

The CIP process involved the screening of the cyanide pulps to remove any large particles or woodchips that might possibly block the interstage screens, before granular carbon is added to adsorb the gold complex. The gold is usually eluted from the loaded carbon by washing it with a strong caustic cyanide solution an elution column at temperatures higher than 90 °C. Gold is recovered from the concentrated eluate either by electrowinning or zinc cementation. After thermal regeneration to remove the organic and inorganic impurities that are adsorbed during the adsorption cycle, the spent carbon is returned to the adsorption process.

By far the greatest body of knowledge on the CIP process that has formed its way into the public domain is the publications covering fundamental research. These studies have contributed significantly to the understanding of the process, and some of the important results will be presented here.

**MECHANISM OF GOLD ADSORPTION**

No agreement has yet been reached regarding the mechanism by which metal cyanides are adsorbed onto activated carbon. The more important mechanisms proposed for the adsorption of gold from alkaline solutions can be grouped mainly into four categories:

1. **Adsorption as M⁩⁺(Au(CN)₂)ₙ**
   Davidson (1974) proposed a mechanism in which the extent of adsorption depends on the concentration and character of the "spectator" cations (M⁺) present in the solution.

2. **Adsorption as, M⁩⁺(Au(CN)₂), followed by partial reduction** McDougall et al. (1980) suggested that the initial stage of adsorption involves the adsorption of the less soluble M⁩⁺(Au(CN)₂)ₙ complex (M⁺ = Ca²⁺, H⁺, Na⁺, K⁺)

3. **Adsorption of Au(CN)₂ followed by partial degradation** Au CN (Tsuchida and Muir, 1986)

ELUTION OF GOLD

The main methods used in industry for the elution of gold from activated carbon are the Anglo American Research Laboratories (AARL) method, consisting of a pre-soaking step with a hot caustic cyanide solution followed by rinsing with hot deionised water, and the Zadra process, in which warm cyanide solution is circulated through an elution column and electrowinning. Although simple models exist for the Zadra process, Van Deventer and Van der Merwe (1994) developed a generalised model to simulate the more complex AARL process. Equilibrium conditions may be assumed in an elution column when adsorption is weak, while diffusional phenomena become rate controlling when desorption is weak towards the end of an elution cycle.

BED VOLUMES

- High Diffusivity
- Equilibrium
- Low Diffusivity

Figure 1: shows typical elution profiles predicted by equilibrium and diffusion models.

Although the theory concerning the adsorption process with its underlying sub-processes such as continuous leaching, competition from base metals, fouling of the carbon by organic and inorganic material, shifting equilibrium during adsorption as well as the auxiliary unit operations such as elution, acid washing and thermal regeneration of spent carbon have been studied extensively (Petersen and Van Deventer, 1991), the knowledge had only an incremental impact on the operation of CIP-plants. The largest developments to the CIP process have come in the area of process engineering.

RESIN-IN-PULP

Due to the increased processing of ores that have a low grade and a complex minerology, the current challenge is to develop new technology that will revolutionise the gold industry. Earlier work (Fleming and Cromberge, 1984) showed that resins have some distinct advantages over activated carbon for the recovery of gold from cyanide leach liquors. Resins have potentially higher loading capacities and loading rates, are less likely to be poisoned by organic matter such as lubricants and flotation reagents, and do not require thermal regeneration.

Most of the contributors to RIP were in the areas of the development of new resins with superior physical and chemical (gold selectivity) properties and viable elution schemes for weak and strongbase resins. Although the world’s first commercial application of RIP technology for gold recovery occurred in the Soviet Union in 1978, this technology has not been accepted by a sceptical gold industry in the Western World.

As a result of the depressed gold price, there is a world-wide trend towards low-cost heap-leaching operation. Heap leaching provides relatively low-grade, clean solutions from which the gold has to be recovered. Resin-in-solution (RIS) has become an alternative for upgrading of gold from clarified solutions. (Van Deventer, et.al, 1999). In a techno-economic comparison between CIP and RIP done by Johns and Marsh (1993), it was found that at low tonnages, CIP is between 20 and 62 % more expensive to build and between 80 and 120 % more expensive to run than the RIP process, and at high tonnages, CIP is between 11 and 29 % more expensive to build and between 39 and 69 % more expensive to run than the RIP process. It has also been shown that resins could be used to recover base metals and the recycling of cyanide (Leao, et.al, 1998). Van den Berg and Petersen (2000) showed that ion exchange resin in combination with a surfactant, can drastically reduce the pregrobbing effect in gold adsorption.

BIOLEACHING

Bioleaching is now an established technology for the pre-treatment of refractory gold ores and concentrates. In many cases, it offers economic, environmental and technical advantages over pressure oxidation and roasting. (Van Aswegen, 1993; Paulin and Lawrence, 1996). The Ashanti Goldfields Company (AGC) operates the world’s largest bio-oxidation plant using the BIOX technology.

The BIOX technology has proved to be reliable, flexible, efficient and environmentally friendly.
(Egya-Mesah and Amebley, 1999). A schematic flow diagram of the Ashanti BIOX plant is shown in Figure 2.

![Flow Diagram of Ashanti BIOX Plant](image)

Figure II: Ashanti Bion plant flow diagram

It has been observed that the extent of oxidation required to liberate an equivalent amount of gold is greater with pressure oxidation than bacterial oxidation, particularly where the concentrate arsenic bearing effluents is a controversial subject. However, experience to date indicates that simple neutralisation with lime and precipitation of arsenic as basic ferric arsenate is effective and the residues produced exhibit long term stability.

A solvent-extraction route developed at Mintek for chemical refining of gold from chloride media has shown considerable promise for the selective recovery of gold. The Minataur process comprises of three unit operations, as shown in Figure 3.

![Flow Diagram of Minataur Process](image)

Figure III: The Minataur process

Advantages of this process over conventional electrorefining technology include the significantly reduced lock-up times of the gold, the ease of operation and control, and the ability to produce a high-purity product in a very forgiving circuit. The economics of the process are extremely attractive, as depicted in Table 1 which shows the estimates of the capital and operating costs for a plant of 24 t/a capacity.

<table>
<thead>
<tr>
<th>COST ITEM</th>
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<tbody>
<tr>
<td>Capital (R)</td>
<td>3 450 000</td>
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<tr>
<td>Operating Cost (R/a)</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>312 000</td>
</tr>
<tr>
<td>Fixed</td>
<td>505 000</td>
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<tr>
<td>Cost (R/kg Au)</td>
<td>63</td>
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<tr>
<td>Cost (US $/oz Au)</td>
<td>0.44</td>
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*An exchange rate of R7.41 = US $ 1.00*
ALTERNATIVE LIxivIANTS

Over the past hundred years, cyanide accounted for a growing proportion of world gold production. In particular, it made possible the exploitation of low-grade, so-called “invisible” gold beyond the reach of gravity separation, and also assisted to reduce the use of a truly harmful reagent, mercury. Over the last few years there has been an intensive effort to identify lixiviants other than cyanide for gold leaching. Although traditional cyanidation remains the overwhelming choice for treating free milling gold ores, there are certain classes of ore and concentrates that are considered refractory. The inability of conventional cyanidation to treat these materials effectively, as well as the growing awareness of the detrimental affects of pollution on the environment, is still prompting the search for more powerful lixiviants. Amongst these lixiviants, thiourea, bromine, iodine, thioulsulphate and thiocyanate have been investigated (Von Michaelis, 1987; Teirlinck and Petersen, 1993). Figure 4 shows the dissolution rate of gold in various lixiviants.

INDUSTRIAL APPLICATIONS

Anglo gold, the world’s largest gold producer and Mintek, South Africa’s national metallurgical research organisation, recently launched a pioneering joint initiative to pursue the research and development of industrial applications of gold. The project focuses on the application of gold in catalysis, and in particular, on the metal’s role in facilitating the catalysis of chemical reactors in industrial areas of economic and social significance.

Those catalysts could find application in office buildings, in the purification of air for the occupants of passenger aircraft, and as a general solution to air pollution. Furthermore, there is technological proof that gold has potential application in certain types of fuel cells that provide environmentally friendly power and in heavy industry chemical synthesis.

CONCLUSIONS

A review on the advances in the extraction, processing and application technologies of gold is presented. It shows that, although fundamental research has contributed significantly in the understanding of sub-processes related to gold, the greatest contributions were in the area of process engineering. Due to the increased processing of ores that have a low grade and a complex mineralogy, the challenge will be to seek for alternative adsorbents which are selective, abrasion-resistant and have the ability to enhance the extraction of gold from refractory and pregrobbing ores. Although cyanide is very effective for gold dissolution, the fact that cyanide is becoming under close scrutiny of environmental legislature, alternative lixiviants is sought. It is also demonstrated that gold has unique properties that can be utilized optimally and profitably in applications.

REFERENCES


