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The simulation of gold adsorption by carbon using a film diffusion model

By M.W.Johns

THE SIMULATION OF GOLD ADSORPTION BY CARBON USING A FILM DIFFUSION MODEL

Mark William Johns

A dissertation submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 1987.

DECLARATION

I declare that this dissertation is my own, unaided work, except where specific acknowledgement is made. It is being submitted for the Degree of Master of Science (Engineering) to the Faculty of Engineering, University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other university.

MLW Johns

Mark William Johns

28th day of July 1987

ABSTRACT

Experimental work showed that the adsorption of the aurocyanide ion by activated carbon is under film diffusion control until the carbon reaches 70 per cent of its equilibrium loading capacity. A rate expression based on the classical film diffusion rate expression is suggested and the model for the batch test developed. The proposed model is shown to simulate batch adsorption tests at different ratios of carbon mass to solution volume.

The mass transfer coefficient was linked to the carbon particle size and agitation rate by the use of dimensionless numbers. Correlations are suggested for fixed beds, fluidized beds and rolling bottles. It was determined experimentally that, at equivalent Reynolds numbers, the fixed bed provides the optimum system for mass transfer.

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LIST OF SYMBOLS

Area of carbon	m^2	A_c
Mass of carbon	kg	m_c
Mass of solution	kg	m_s
Volume of solution	m^3	V_s
Density of solution	kg m^{-3}	ρ_s
Equilibrium constant	-	K
Liquid side mass transfer coefficient	m s^{-1}	k_l
Rate	mg m^{-3} s^{-1}	r
Time	s	t
Concentration of gold in solution at time t	mg kg^{-1}	C_s
Concentration of gold in solution at time o	mg kg^{-1}	C_s^o
Concentration of gold in solution at time ∞	mg kg^{-1}	C_s^e
Concentration of gold on carbon at time t	mg kg^{-1}	C_c
Concentration of gold on carbon at time o	mg kg^{-1}	C_c^o
Concentration of gold on carbon at time ∞	mg kg^{-1}	C_c^e
Freundlich constant	-	a
Freundlich power	-	b
Reynolds number	-	Re
Schmidt number	-	Sc
Sherwood number	-	Sh
Viscosity	kg m^{-1} s^{-1}	η
Diffusivity	m^2 s^{-1}	D
Particle diameter	m	d_p
Voidage fraction		ϵ
Linear velocity	m s^{-1}	u

LIST OF SYMBOLS

Area of carbon	m^2	A_c
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Time	s	t
Concentration of gold in solution at time t	mg kg^{-1}	C_s
Concentration of gold in solution at time o	mg kg^{-1}	C_s^o
Concentration of gold in solution at time ∞	mg kg^{-1}	C_s^e
Concentration of gold on carbon at time t	mg kg^{-1}	C_c
Concentration of gold on carbon at time o	mg kg^{-1}	C_c^o
Concentration of gold on carbon at time ∞	mg kg^{-1}	C_c^e
Freundlich constant	-	a
Freundlich power	-	b
Reynolds number	-	Re
Schmidt number	-	Sc
Sherwood number	-	Sh
Viscosity	kg m^{-1} s^{-1}	η
Diffusivity	m^2 s^{-1}	D
Particle diameter	m	d_p
Voidage fraction		ϵ
Linear velocity	m s^{-1}	u

1 INTRODUCTION

This introductory chapter discusses the use of carbon in the extraction of gold by looking first at the historical development and then at its practical uses. The theoretical aspects of gold cyanidation and adsorption are presented. The models presently available for the simulation of gold adsorption by carbon are reviewed. The objectives of this research project are then presented.

1.1 THE USE OF CARBON IN THE EXTRACTION OF GOLD

In the introductory sections of their papers, Laxen[1,2], Fleming[3], Dahya[4], and McDougall[5] provide adequate discussions on the historical development of carbon-in-pulp (CIP) and the use of carbon in the extraction of gold. The following précis originates from these works.

The first mention of the ability of carbon to adsorb precious metals was made in 1847. In 1890, McArthur and the Forrest brothers discovered that cyanide was a good solvent for gold. In 1894, Johnson found that charcoal can be used to recover gold from cyanide solutions. The charcoal in those days was prepared by heating wood to red heat and quenching it, but the carbon produced did not possess the adsorption abilities of today's carbon. Another factor against carbon at that time was that no elution procedure was known. Carbon reached its maximum use in Australia in 1917, when fine carbon was used to recover gold from pregnant solutions, but, as the zinc

cementation process advanced, interest in carbon declined.

It was not until after the Second World War that a carbon was developed with a higher activity and greater resistance to abrasion, and in 1952 Zadra suggested the caustic cyanide elution procedure. These advances removed the major obstacles in the path of CIP development to economic plant scale. The first major CIP plant (treating the slimes fraction) was built at Homestake, U.S.A., in 1973.

CIP replaces the filtration and clarification sections of the old gold process. The advantages of CIP over the old process are:

* lower capital and operating costs

* the ability of carbon to adsorb gold is not affected by any of the common constituents of cyanide leach liquors

* the carbon granules are added directly to the cyanided pulp, which obviates the need for the expensive filtration and clarification stages

* the soluble gold losses are usually significantly lower than those on a conventional plant

* in general, CIP is favoured in a high-flow, low gold concentration situation.

The objective in the development of carbon-in-pulp in South Africa was different from that of the American plants, in that the total cyanide pulp was to be treated, not just the slimes fraction. In 1974, Anglo

American Research Laboratories and the National Institute for Metallurgy (now the Council for Mineral Technology) began laboratory-scale testwork, and by 1976, a small-scale rig was used on Blyvooruitzicht pulp. To date, numerous carbon-in-pulp plants have been erected. These plants treat a wide variety of feed materials, and some examples are listed below:

* new gold treatment plants (Doornkop)
* modernised gold plants (Grootvlei)
* replacement of filter plants (Harmony)
* new dump reclamation plants (Crown Sands).
* expanding production (Kinross)
* scavenging of gold from filter plant residue (Western Areas)
* treatment of return dam solutions (Welkom)

Carbon-in-pulp plants in South Africa are at present treating 4,5 million tons of ore per month, and plants to treat a further 1,7 million tons per month are planned.

The carbon-in-pulp circuit, as used on a typical gold mine, is as follows: There are four to seven flat-bottomed contactors in the circuit. The feed material is the cyanided pulp from the leaching section, which has been screened to 0,6 mm prior to entering the first contactor. The pulp has a solid concentration of 40 to 45 per cent and a residence time of one hour per stage. Pulp flows by gravity down the plant. Carbon is contained in each contactor at a concentration of 15 to 25 grams per litre of pulp. Within each contactor is an interstage screen (aperture 0,85 mm), the purpose of which is to hold the carbon within a stage while letting the pulp flow down the train. In South Africa, the most commonly used form of agitation in the contactors is the

draft tube. The pulp is screened at the end of the train to remove abraded carbon. The carbon has a residence time in the circuit of 8 to 12 days. Carbon is moved counter-current to the flow of pulp by means of air-lift pumps.

The loaded carbon is removed from the top contactor and sent for elution. Elution involves a presoak in a caustic cyanide solution, followed by passing hot water (110°C) through the carbon bed to elute the gold from the carbon. The gold in the eluate is recovered by electrowinning. The carbon is reactivated in a rotary kiln prior to being sent back to the adsorption circuit.

1.2 THEORETICAL ASPECTS OF GOLD CYANIDATION AND ADSORPTION

McArthur and the Forrest brothers discovered that cyanide is a good solvent for gold. The reaction, as explained by Hejja[6], and now generally accepted, was first suggested in 1896 by Bodlander:

$$2Au + 4NaCN + O_2 + H_2O \rightarrow 2Na\ Au(CN)_2 + 2NaOH + H_2O_2$$

On the subject of the structure of the carbon, McDougall[5] provides an excellent discussion. Included in her paper is a review of the different theories on the mechanism by which carbon loads gold cyanide. The discussion which follows is a summary of her work. Those references quoted in this section which are indicated by author and year of publication are listed at the end of McDougall's review paper[5].

Activated carbon is a generic term for a family of substances, none of which can be characterized by a single formula or by chemical analysis. X-ray diffraction has shown that the structure of activated carbon is similar to that of graphite. In graphite, layers of fused hexagons are held apart by van der Waal's forces. Activated carbon consists of tiny graphite-like platelets, only a few carbon atoms thick, which form the walls of open cavities of molecular dimensions. The hexagonal carbon rings (many of which have undergone cleavage) are randomly orientated. The overall structure is very disordered and is referred to as "turbostatic".

Activation refers to the process by which pre-charred carbonaceous raw material (pips, coal, shells) is made to develop a porous structure. This is achieved at high temperature in the presence of oxidizing agents, for example, steam.

The mechanism by which activated carbon loads gold cyanide has interested and puzzled researchers since 1913. The theories can be split into earlier and modern proposals.

Early theories

The earlier theories can be split into two groups:

* those that proposed that the $Au(CN)_2^-$ ion is adsorbed, and

* those that proposed that the $Au(CN)_2^-$ complex is chemically altered by reduction to metallic gold or some intermediate state.

Feldtmann (1914) postulated that gold cyanide loaded by a chemical precipitation mechanism involving a combination of AuCN, CO and $(CN)_2$, i.e. $AuCNCO(CN)_2$. Edmonds (1917) suggested that the complex is $KAu(CN)_2CO$ or $HAu(CN)_2CO$.

Allen (1918) found that the loading of gold cyanide onto charcoal could be accurately described by the Freundlich equation, which, in the case of true adsorption phenomena, relates the amount of material adsorbed to the concentration of solute remaining in solution at equilibrium. He proposed that gold cyanide is physically adsorbed as $NaAu(CN)_2$. Williams (1923) found that the sodium content of the ash of loaded, burnt charcoal was far from sufficient to account for simple adsorption, as suggested by Allen. He suggested that the $Au(CN)_2^-$ ion is adsorbed.

Gross and Scott (1927) undertook the first systematic investigation of adsorption, and proposed that $Au(CN)_2^-$ loaded without undergoing chemical change and is retained on the carbon as the neutral complex, $M^{n+}[Au(CN)_2^-]_n$, where M varies depending on the nature of the solution.

Modern theories

Garten and Weiss (1957) offered an alternative explanation for the experimental results of Gross and Scott, and suggested that $Au(CN)_2^-$ anions are loaded onto carbon by an anion exchange mechanism involving simple electrostatic interaction between positive and negative charges.

Kuzminykh and Tjurin (1969) argued that the presence of simple anions had no effect on capacity, so the interactions between gold cyanide and carbon could not be electrostatic in nature. Since neutral organic molecules depress gold capacity, the authors proposed that the gold adsorbate is a neutral molecule.

Davidson (1974) proposed that gold is adsorbed as $M^{n+}[Au(CN)_2^-]_n$. When M is an alkali earth metal, the ion pair is bound to the carbon more firmly than when M is an alkali metal ion. This led to the suggestion that a presoak before elution would convert the firmly bound ion-pair into a more readily desorbable species.

Dixon, Cho and Pitt (1976) advanced a mechanism that involved an electrostatic attraction between $Au(CN)_2^-$ anions and positively charged sites on the surface of the carbon, as previously suggested. More recently (1979) they modified their earlier theories and postulated a mechanism that depended on the degree and type of ionic hydration, that is, the adsorption reaction is considered to be due more to physisorption than to chemisorption.

McDougall *et al* (1980) demonstrated that the large, weakly-hydrated anion ClO_4^- (similar to $Au(CN)_2^-$) present in solution did not depress the gold loadings, and they therefore concluded that the adsorption could not be attributed to simple electrostatic interactions, as proposed by numerous workers. By applying X-ray photoelectron spectroscopy to loaded carbon, McDougall *et al* were able to ascertain that the oxidation state of the gold in the gold cyanide adsorbate, irrespective of loading conditions, was neither one, as required for the presence of $Au(CN)_2^-$ on the carbon, nor zero, which would indicate metallic gold, but an intermediate 0,3.

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