

The effect of temperature on the desorption of gold cyanide from activated carbon

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Abstract

Activated carbon is used worldwide for the extraction of gold cyanide from leached pulps. The elution of gold cyanide is usually conducted by soaking the loaded carbon in an alkaline solution of cyanide in a column, followed by a rinse with water at temperatures higher than 100°C. Because the effects of temperature, cyanide addition and ionic strength are confounded to an extent, little has been published with which to model the dynamic behaviour of this complex process. An attempt is made in this paper to isolate and quantify the effect of temperature on the desorption of gold from activated carbon. A mathematical model for the desorption process is presented in a summarized form, and is shown to predict experimental data satisfactorily. An increase in temperature results in a decrease in the adsorption and in an increase in the decomposition of cyanide. An activation energy of 87.1 kJ mol⁻¹ was determined for the decomposition of cyanide, which occurs mainly by hydrolysis at elevated temperatures. The isosteric heat of adsorption of gold cyanide decreased from 18.2 to 8.8 kJ mol⁻¹ when a pre-treatment of cyanide was used prior to desorption. Therefore, the gold equilibrium becomes less sensitive to temperature after pre-treatment with cyanide. The desorption of gold cyanide seems to be more sensitive to the cation concentration at high temperatures. An increased temperature increases the maximum of the elution profile, and therefore enhances significantly the dynamics of desorption.

INTRODUCTION

The carbon-in-pulp (CIP) process has gained increasing international acceptance as the main method for extracting gold from leached pulps since its inception towards the end of the 1970s [1]. In an earlier paper it was shown that the adsorption of gold cyanide onto activated carbon has been researched thoroughly, while the desorption of gold from the carbon has not received much attention [2]. Hence, many opportunities exist for research on the mechanism and dynamics of the desorption process.

Three methods of elution are mainly used in industry [3]: (a) the Zadra

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process in which warm cyanide solution is circulated through an elution column and an electrowinning cell (a U.S. Bureau of Mines invention); (b) the Anglo American Research Laboratory (AARL) method consisting of a pre-soaking step with hot caustic cyanide solution followed by elution with hot deionized water (a South African invention); (c) the use of organic solvents, which involves variations of (a) and (b) (an Australian invention). In general the AARL method is preferred due to lower operating costs, especially with the development of continuous elution.

Cyanide and hydroxide salts are added during both the AARL and Zadra elution procedures to enhance the elution of the gold cyanide. The equilibrium between the adsorbed gold and the gold cyanide in solution is affected by the concentrations of these additives, which change continuously [4]. Both the equilibrium of adsorption/desorption and the degradation of the cyanide are affected significantly by temperature. Adams and Nicol [5] listed the most significant influences on elution, in order of decreasing importance, as follows: temperature, cyanide and hydroxide concentrations, and the ionic strength of the eluant. Likewise, Davidson [6] considered the temperature and reagent cyanide addition to be the most important factors affecting gold elution. In cases where the loaded carbon contained large amounts of calcium carbonate, the temperature and acid washing of the carbon were considered to be most important for efficient elution [7].

Davidson [6] stated that the effects of temperature, reagent cyanide addition and ionic strength are confounded to such an extent that it is "not possible to quantify each parameter in isolation". Nevertheless, an attempt is made in this paper to isolate and quantify the effect of temperature on the desorption of gold from activated carbon. It will be shown that temperature affects many of the sub-processes constituting the elution procedure.

REVIEW OF PREVIOUS RESEARCH

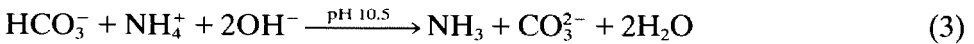
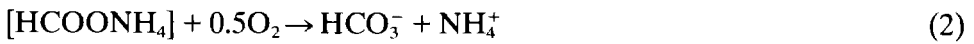
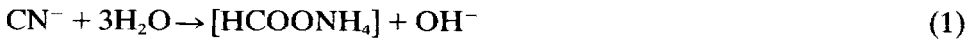
The adsorption of gold onto activated carbon is an exothermic process [8] and an increase in temperature will shift the equilibrium to favour desorption. Temperature is considered to be the most important factor in the efficient elution of gold and other metal cyanides from activated carbon [5, 6]. It was found that an increase in elution temperature from 90 to 110°C improved significantly the elution efficiency and maximum eluate concentration for all types of activated carbon tested [7].

McDougall et al. [9] related the need for high elution temperatures to the more than 14 times higher solubility of $\text{KAu}(\text{CN})_2$ in hot rather than cold water. They further reported that plots of the logarithm of the equilibrium solution-phase concentration versus the reciprocal of the absolute temperature in Kelvin gave a set of straight lines. From these plots, an average value for the isosteric heat of adsorption was calculated as 42 kJ mol^{-1} . Similar

linear relationships were found by plotting the distribution of gold between the solid and liquid phases at equilibrium (Q_e/C_e) versus $1/T$ for two sets of data with different initial gold concentrations [10]. However, neither of these authors considered the effect of temperature on the shape of the equilibrium curve.

It is well known that cyanide decomposes simultaneously with the elution of gold [11]. Hence, it is important to determine the effect of temperature on the decomposition of cyanide, which occurs via several reactions [12]. Of these, the following reactions are considered to be the most important [13].

Hydrolysis



Oxidation



The oxidation reactions are catalysed by the presence of activated carbon. According to Nicol [13], the decomposition of cyanide is very slow at room temperature, unless carbon is present. He further observed that the effect of the presence of carbon decreased with an increase in temperature. Hence, the hydrolysis reaction is dominant at high temperatures, whereas the catalytic oxidation reaction is more significant at low temperatures. Muir et al. [14] also regarded the hydrolysis reaction as the main mechanism for the loss of cyanide during Zadra or AARL elution. The rate of hydrolysis was found to be more temperature sensitive than the rate of oxidation. Despite these observations, little effort has been made to quantify the effect of temperature on the overall elution process. This paper is a first attempt to incorporate temperature in an overall mathematical model for the desorption of gold from activated carbon.

EXPERIMENTAL

Materials

An industrial, eluted activated carbon from the Beatrix mine in South Africa was used in all experiments. Prior to use, the carbon was

acid-washed and rinsed with deionised water to remove as many impurities as possible. This carbon had an apparent density of 839 kg m^{-3} , a BET surface area of $792 \text{ m}^2 \text{ g}^{-1}$, an average particle size of 1.42 mm, a pore volume of $6.34 \times 10^{-4} \text{ m}^3 \text{ kg}^{-1}$ and a void fraction of 0.292 in a packed column. Van der Merwe [15] showed that no AuCN was formed on the carbon during adsorption from alkaline solutions at room temperature.

Pure potassium salts of aurocyanide, cyanide and hydroxide were used. The pretreatment step for AARL-type elutions involved soaking the carbon in a KCN solution. Because no acid treatment was conducted, no KOH was normally added to the pre-treatment solution. The high concentration of cyanide in the pre-treatment step ensured sufficiently high pH values in the pre-treatment step as well as in the subsequent elutions. The pH of the distilled water used as eluant was also not adjusted. Samples of eluate were analysed for gold and potassium by atomic absorption, and for cyanide by titration with silver nitrate and potassium iodide as indicator.

Batch tests

Batch experiments were conducted in 1-litre stirred reactors, fitted with reflux coolers so as to minimize evaporation at elevated temperatures, and immersed in a temperature-controlled water bath. The equilibrium conditions were determined after a period of 3 weeks by atomic absorption analysis of the solution samples. The pH values and the concentrations of reagents used in the quantification of the various effects were measured at the same time as the equilibrium gold concentrations. Because it was proved earlier [15] that the equilibrium isotherms for adsorption and desorption of gold in contact with this carbon are the same, all the equilibrium data presented here were determined for adsorption.

Elution columns

Most runs were conducted in a glass column surrounded by a temperature-controlled water jacket. This column had a bed height of 13.7 cm and an internal diameter of 1.22 cm. One bed volume of the column contained 9.5 g of dry carbon. A bed volume (BV) is defined as the empty volume of the reactor that is occupied by the packed bed of carbon.

After pre-treatment outside the column in a glass beaker, the carbon was separated from the solution with a sieve, and excess pre-treatment solution was removed by blotting with filter paper. The carbon was then dropped into the glass column containing half a bed volume of eluant at the elution temperature; the starting time for the elution was taken as the moment when flow of eluant was introduced. The flow rate was monitored continuously. Pre-heating of the feed was accomplished by keeping the section of the column above the carbon bed filled with eluant.

A stainless-steel column with a hot-oil jacket was used for comparative tests on a larger scale and for runs at higher temperatures than were possible with the glass column. This column had a bed height of 75.0 cm and an internal diameter of 10.0 cm. One bed volume of this column contained 3 500 g of dry carbon. A heat exchanger was used to pre-heat the feed to the operating temperature of the column, with the outlet temperature of the eluate being controlled. At temperatures higher than 90°C, the column was pressurized by the use of a valve on the outlet of the column. The eluate was cooled by passing it through a coil that was submerged in cold water.

MATHEMATICAL MODELLING OF THE DESORPTION PROCESS

It is not the purpose of this paper to explain the features of the system of differential equations required to simulate the various sub-processes occurring during desorption. Rather, such models will be summarized here, which then provide a basis for discussing the experimental and computational results on the effect of temperature. Van der Merwe [15] discussed in detail the mathematical and computational aspects of the models for the different sub-processes.

Simple models [16, 17] have been proposed for the Zadra process, but few attempts [18] have been made to model the more complex AARL process, in which the equilibrium curve shifts as the spectator cations are displayed from the column. Whereas previous models could be applied only to specific conditions, a modelling approach which takes all the sub-processes into account is of general use in Zadra, AARL, organic solvent and continuous elution processes [15].

The equilibrium of desorption cannot be modelled by taking only the pH, the level of free cyanide in solution (C_N), the concentration of spectator cations (C_K) and the temperature (T) into account [15]. Especially at the high temperatures and cyanide levels encountered during pre-treatment, the quantity of decomposed or adsorbed cyanide, designated the “cyanide age” of the carbon (Q_N), is most important in determining the equilibrium [4]. When a Freundlich-type isotherm ($Q_c = AC_c^n$) relating the equilibrium gold loading on the carbon (Q_c) to the gold concentration in solution (C_c) is used, A is related to n by an inverse linear function [4]. The following type of expression could be determined for A

$$A = A_0 [1 / (aQ_N + 1)] \exp(E_a / R_0 T) (C_N + 1)^{-c} (C_K + 1)^d \exp(-epH) (V_B + 1)^q \quad (6)$$

where A_0 , a , c , d , e and q are positive empirical constants which are specific to the type of carbon and the nature of the pre-treatment step. E_a is the isosteric heat of adsorption, and R_0 is the universal gas constant. V_B is the number of bed volumes passed through the carbon bed, and $(V_B + 1)^q$

accounts for the reactivation of the carbon surface due to the removal of decomposition products. The equilibrium curve therefore shifts as C_N and C_K change during a run, depending on the contacting system used [4].

A plug flow model to describe the profile of free cyanide during a run can be based on the following assumptions: the oxidation and hydrolysis reactions of the cyanide in the pores of the carbon can be combined and described by a single first-order reaction; the concentration of cyanide inside the pores of the carbon is homogeneous; mass transfer between the bulk solution and the pore liquid occurs via film diffusion; the combined decomposition rate of cyanide in the pores will decrease with an increase in the “cyanide age”, which means that the carbon surface becomes passivated [15].

A mass balance for cyanide in the pore liquid gives

$$\partial C_{Np} / \partial t = 6k_s(C_N - C_{Np}) / (\sigma V_p d_c) - k_{Np} C_{Np} \quad (7)$$

where C_{Np} is the concentration of cyanide in the liquid phase in the pores of the carbon, C_N is the concentration of cyanide in the interparticle solution, k_s is the film transfer coefficient for cyanide, k_{Np} is the rate constant for the decomposition of cyanide in the pores of the carbon, σ is the apparent density of the carbon, V_p is the specific pore volume, d_c is the average diameter of a carbon particle, and t is the time variable.

A mass balance of cyanide in the interparticle solution in the elution column gives

$$(\partial C_N / \partial t) = -V(\partial C_N / \partial h) / (S\varepsilon) - 6k_s(1 - \varepsilon)(C_N - C_{Np}) / (\varepsilon d_c) - k_N C_N \quad (8)$$

where ε is the void fraction in the bed of carbon, S is the flow area of the column, h is the axial variable in the column, k_N is the rate constant for the decomposition of cyanide in the interparticle solution, and V is the volumetric flow rate of eluant.

The change in the “cyanide age” of the carbon was calculated from the rate of decomposition of cyanide in the pores of the carbon

$$\partial Q_N / \partial t = V_p k_{Np} C_{Np} \quad (9)$$

It can be expected that temperature will affect the rate constant k_N for the decomposition of cyanide in the interparticle solution through an Arrhenius relationship

$$k_N = b \exp(-E_N / R_0 T) \quad (10)$$

where b is an empirical constant and E_N is the activation energy for the decomposition of cyanide in the interparticle solution. According to van der Merwe [15], the effect of “cyanide age” on k_{Np} is given by

$$k_{Np} = f / (Q_N + 1)^g \quad (11)$$

where f and g are empirical constants; f could be replaced by an

Arrhenius-type expression

$$k_{\text{Np}} = [b' / (Q_{\text{N}} + 1)^g] \exp(-E_{\text{Np}} / R_0 T) \quad (12)$$

where b' is an empirical constant dependent on the characteristics of the activated carbon, and E_{Np} is the activation energy for the decomposition of cyanide in the carbon pores.

In contrast with the elution profiles of cyanide, the profiles of spectator cations all reveal long tails, which indicate some degree of dispersion or desorption from micropores. Neither Levenspiel's dispersion model, nor the stagnant region model of Wakeman, nor the pore diffusion model of Leyva is capable of describing these tails [15]. Furthermore, it has been observed that the profiles of spectator cations are independent of flow rate. A tanks-in-series non-ideal flow model with two deadwater regions per stage simulates the cation profiles satisfactorily at various flow rates and initial concentrations [15].

Both surface and pore diffusion models describe elution profiles of gold equally well [15]. If the desorption reaction is instantaneous, so that equilibrium exists between the solute in the liquid phase and the adsorbed phase on the carbon, the elution of gold is independent of flow rate under conditions of strong desorption.

A material balance for gold cyanide over the column is

$$[S\sigma V_p(1 - \varepsilon) + S\varepsilon](\partial C / \partial t) + S\sigma(1 - \varepsilon)(\partial Q / \partial t) = V \partial C / \partial h \quad (13)$$

It follows from the assumption that equilibrium exists between the adsorbed and liquid phases, i.e. $Q = AC^n$. Because the equilibrium changes continuously during an elution test, both A and n are functions of time. Van der Merwe [15] presented details of the numerical procedures used to solve these models.

RESULTS AND DISCUSSION

Equilibrium curves

In an attempt to minimize the parameters in the Freundlich isotherm, the values of A and n determined for more than ten different carbons under different adsorption conditions [19] were plotted by van der Merwe [15]. He observed that n decreases linearly with an increase in A , and that the Freundlich isotherm for the adsorption of gold cyanide onto activated carbon can be modified to

$$Q_e = AC_e^{mA+M} \quad \text{where} \quad n = mA + M \quad (14)$$

where m and M are empirical constants which should be determined from experimental data. With only the one unknown A in the equilibrium expression, it is now possible to describe the equilibrium at a certain

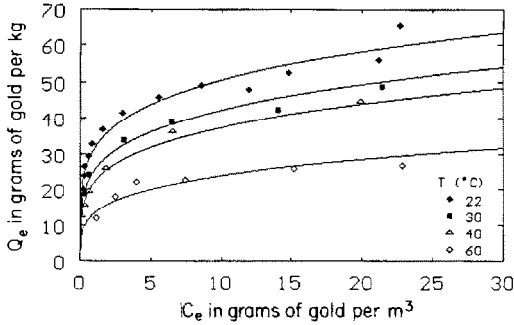


Fig. 1. Equilibrium data for the adsorption of gold cyanide onto activated carbon. Curves calculated from average A values with eqn. (15).

combination of factors with only one value of Q_e and C_e . By keeping all factors constant and changing only one factor at a time, it is thus possible to quantify the effect of each factor on the value of A , and therefore its effect on the gold cyanide equilibrium.

Figure 1 presents equilibrium data determined for gold cyanide adsorption onto carbon at 22, 30, 40 and 60°C. Higher temperatures would have necessitated the addition of cyanide to prevent the formation of AuCN [15]. As cyanide is readily hydrolysed at high temperatures, it would have been impossible to determine all equilibria at the same cyanide concentration. The A and n values, determined by fitting the Freundlich equation to the four sets of experimental data in Fig. 1, are summarized in Table 1. A least-squares regression on the data in Table 1 provides the following correlation between A and n

$$n = -0.002688A + 0.2902 \quad (15)$$

Hence, the curves in Fig. 1 are represented by the equation

$$Q_e = AC_e^{-0.002688A + 0.2902} \quad (16)$$

where the average A values are given by the data points in Fig. 2 for the different temperatures. The main advantage of using eqn. (16) is that it

TABLE 1

Fitted Freundlich parameters for equilibrium adsorption of gold cyanide on carbon at different temperatures

$\theta/^\circ\text{C}$	A	n
22	31.49	0.206
30	25.79	0.221
40	21.84	0.232
60	13.43	0.254

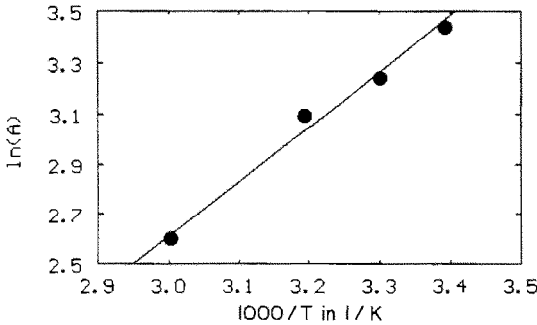


Fig. 2. The effect of temperature on the Freundlich parameter A for the adsorption of gold cyanide onto activated carbon.

contains only one parameter (A), which makes it easier to quantify the effect of a factor such as temperature on the gold cyanide equilibrium. Therefore, all of the A values presented from here onwards, will be calculated with eqn. (16). Figure 2 shows that the logarithm of A plotted against the reciprocal of the absolute temperature yields a straight line, which gives the Arrhenius relationship

$$A = 0.019 \exp(2190/T) \quad (17)$$

This constitutes an isosteric heat of adsorption of 18.2 kJ mol^{-1} , which is significantly lower than the 42 kJ mol^{-1} measured by McDougall et al. [9]. Such large differences are possible due to the wide variation in properties between activated carbons [15]. As will be shown later, a cyanide pre-treatment which modifies the surface of the carbon decreases the isosteric heat of adsorption even further.

Decomposition of cyanide

Figure 3 shows the effect of temperature on the decomposition of cyanide in the absence of activated carbon. The first-order rate constants

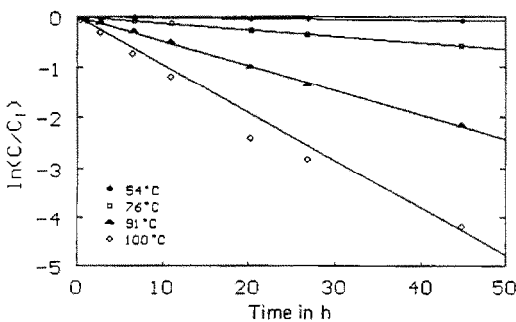


Fig. 3. The kinetics of decomposition of cyanide at different temperatures in the absence of activated carbon. Initial concentration of cyanide, 718 g CN m^{-3} ; volume of batch reactor, 1.5l.

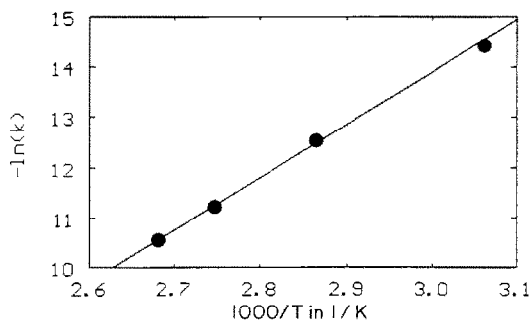


Fig. 4. Arrhenius plot of the rate constant (s^{-1}) for the decomposition of cyanide, as derived from Fig. 3.

determined from these curves are plotted in Fig. 4. As it is impossible to isolate the oxidation and hydrolysis reactions, the plots in Figs. 3 and 4 represent combinations of these two reactions. The rate equation could be calculated as

$$k_N = 4.17 \times 10^7 (\text{s}^{-1}) \exp(-87143/R_0T) \quad (18)$$

This activation energy of 87.1 kJ mol^{-1} is the same as the activation energy for the hydrolysis reaction as reported by Muir et al. [14]. The activation energy of the oxidation reaction is much lower at 36 kJ mol^{-1} [12]. This implies that mainly the hydrolysis reaction occurred in the above experiments which were all conducted at temperatures higher than 50°C . Because the oxidation reaction is less important at higher temperatures, eqn. (18) could be used in the simulation of elution columns.

Pre-treatment conditions

If the gold is adsorbed in the reversible $\text{Au}(\text{CN})_2^-$ form, cyanide can promote the elution of gold by two different mechanisms: (a) competitive adsorption, and (b) reaction with the carbon functional groups. In order to determine the relative importance of mechanisms (a) and (b), elution runs were conducted on two samples of carbon with equal "cyanide ages", but with different ratios of adsorbed to decomposed cyanide. An increase in temperature will result in a decrease in the adsorption and an increase in the decomposition of cyanide. Figure 5 shows that improved elution of gold was obtained after the pre-treatment at the higher temperature of 100°C , where very little adsorption of cyanide would have occurred. A mechanism of displacement of aurocyanide by cyanide during conventional cyanide pre-treatment at elevated elution temperatures can thus be ruled out to a large extent.

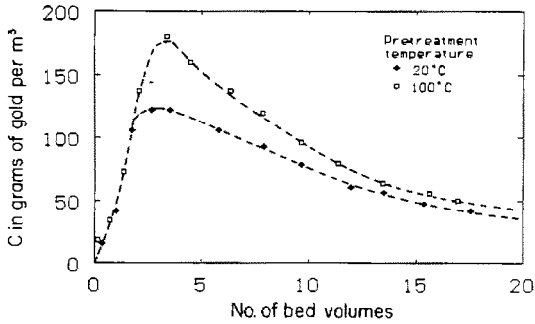


Fig. 5. The effect of the temperature of cyanide pre-treatment on the efficiency of elution of gold cyanide from activated carbon in a glass column. Calculated initial “cyanide age” = $7 \text{ mg CN}^- \text{ g}^{-1}$ carbon for both runs.

Profiles of cyanide elution

The effect of temperature on the calculated profiles of cyanide during elution in the glass column is depicted in Fig. 6. The parameters used are the same as those specified in the Experimental section above, and the decomposition of cyanide in the interparticle solution is described by eqn. (18). For these simulations it is assumed that the deactivation of the carbon surface is independent of temperature, and that the activation energy of the combined reactions inside the carbon pores is 36 kJ mol^{-1} . Other values of parameters used are: $V = 1.367 \times 10^{-8} \text{ m}^3 \text{ s}^{-1}$; $k_s = 2 \times 10^{-6} \text{ m s}^{-1}$; $g = 3.5$; $f = 0.07, 0.26$ and 0.76 s^{-1} at $70, 110$ and 150°C respectively; the ratio of cyanide concentration in the pore liquid to cyanide concentration in the interparticle solution at the end of the pre-treatment step is 0.9 . The initial $Q_N = 3.39 \text{ g CN}^- \text{ kg}^{-1}$ and $C_{Np} = 4100 \text{ ppm}$.

The predicted curve for 70°C corresponds well with the experimental data, which supports the assumptions of the model. Figure 6 shows that an

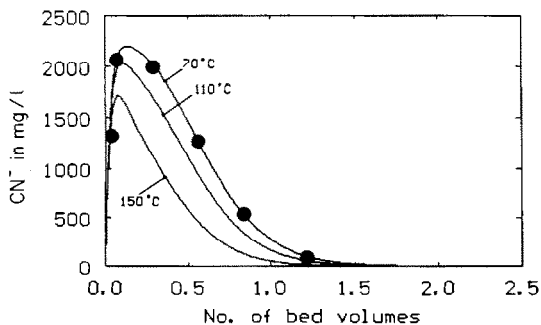


Fig. 6. Predictions of cyanide profiles during AARL-type elutions at different temperatures, and experimental data for 70°C .

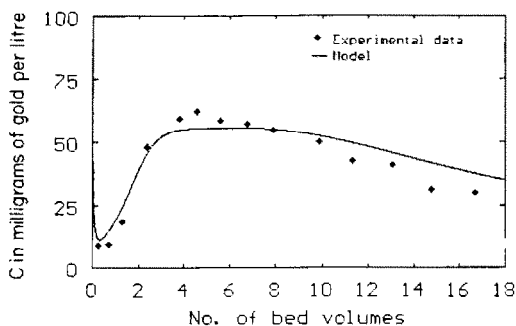


Fig. 7. Simulation of gold cyanide profile during AARL elution in the glass column at 50°C with the equilibrium model. Model parameters are given in Table 2.

increased temperature enhances the degradation of cyanide, and therefore results in a lower maximum of the elution profile.

Profiles of gold elution

The ability of the equilibrium model to simulate gold elution profiles at different temperatures is reflected in Figs. 7–9, which depict runs conducted in the glass column with the carbon pre-treated for 30 min in a solution of 20 g KCN l⁻¹ at 20°C. Table 2 shows that, except for the temperatures, the other conditions were approximately similar in the cases of Figs. 7–9. This is reflected in the ability of the model to simulate all three runs with the same set of parameters by changing only the value of A_0^* , which is defined as

$$A_0^* = A_0 [1 / (aQ_N + 1)] \exp(E_a / R_0 T) (C_N + 1)^{-c} \exp(-epH) \quad (19)$$

The effect of temperature on the elution equilibrium after a cyanide pre-treatment as used for Figs. 7–9 was quantified in Fig. 10 by an Arrhenius plot. It follows from Fig. 10 that the generalized equilibrium

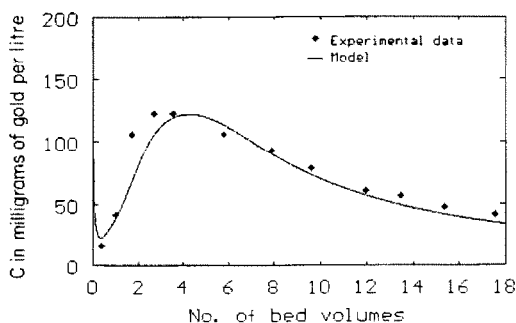


Fig. 8. Simulation of gold cyanide profile during AARL elution in the glass column at 70°C with the equilibrium model. Model parameters are given in Table 2.

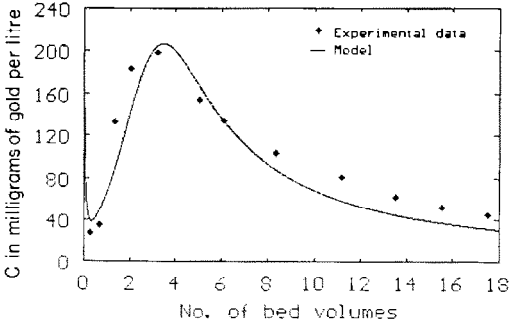


Fig. 9. Simulation of gold cyanide profile during AARL elution in the glass column at 80°C with the equilibrium model. Model parameters are given in Table 2.

TABLE 2

Parameters used in equilibrium model simulations of gold elution profiles in packed columns

	Fig. 7 Glass column	Fig. 8 Glass column	Fig. 9 Glass column	Fig. 10 Steel column
$\theta/^\circ\text{C}$	50	70	80	130
$V \times 10^8 / (\text{m}^3 \text{s}^{-1})$	1.357	1.367	1.249	395.8
Q_{Gi}^a	4.593	4.848	4.976	2.46
A_0^*	0.44	0.375	0.33	0.065
d	0.2	0.2	0.2	0.25
q	0.1	0.1	0.1	0
C_{Kpi}^b	14000	14000	14000	14000
C_{Kdi}^b	0	0	0	7000

^a Q_{Gi} is the initial gold loading on the carbon (g kg^{-1}). ^b C_{Kpi} and C_{Kdi} are the initial concentrations of potassium (ppm) in the carbon pores and interparticle solution respectively.

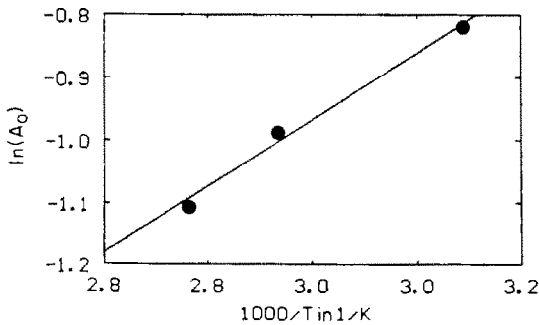


Fig. 10. Quantification of the effect of temperature on the gold elution equilibrium after a pre-treatment with cyanide for the runs in Figs. 7–9.

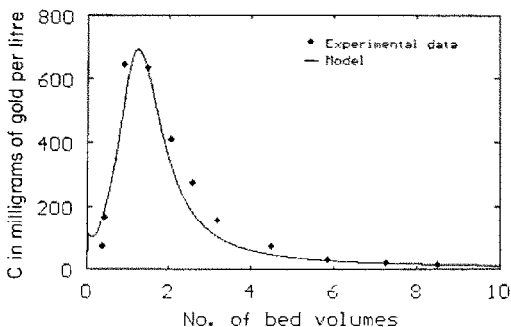


Fig. 11. Simulation of gold cyanide profile during AARL elution in the stainless-steel column at 130°C with the equilibrium model. Model parameters are given in Table 2.

expression for these runs can be written as eqn. (16) where

$$A = 0.016636 \exp(1061/T)(C_K + 50)^{0.2}(V_B + 1)^{0.1} \quad (20)$$

This represents an activation energy of 8.8 kJ mol⁻¹, which is significantly less than the 18.2 kJ mol⁻¹ given in eqn. (17). Therefore, the gold equilibrium becomes less sensitive to temperature after the cyanide pre-treatment used here.

The run in Fig. 11 was conducted in the stainless-steel column, with the carbon pre-treated for 1.5 h in a solution of 20 g KCN l⁻¹ at 125°C. Table 2 shows that an A_0^* value as low as 0.065 had to be used in the simulation due to the high temperature of pre-treatment. If the pre-treatment conditions were similar to those in Figs. 7–9, a value of $A_0^* = 0.237$ could be expected. This confirms the results of Fig. 5, which shows that an increased temperature of pre-treatment yields improved elution. The gold elution also seems to be more sensitive to the cation concentration at this high temperature. No reactivation was included in the simulation, because the pre-treatment was conducted at an elevated temperature. With these modified parameters, the model is capable of fitting the experimental data satisfactorily.

Figures 7, 8, 9 and 11 show that an increased temperature increases the maximum of the elution profile and, therefore, enhances significantly the dynamics of desorption.

CONCLUSIONS

Temperature was found to affect many of the sub-processes constituting the desorption of gold cyanide from activated carbon. An increase in temperature decreases the equilibrium of adsorption and therefore enhances the elution process. The isosteric heat of adsorption is dependent on the condition of the carbon surface, and decreases when the carbon is pre-treated in cyanide. Under practical conditions of elevated temperature,

the degradation of cyanide is caused mainly by hydrolysis, which is accelerated by an increase in temperature according to an Arrhenius relationship. The decomposition products of cyanide render the carbon surface less susceptible to the adsorption of gold cyanide. Therefore, the gold equilibrium becomes less sensitive to temperature after a pre-treatment in cyanide at elevated temperatures. The gold elution also seems to be more sensitive to the cation concentration at high temperatures. An increased temperature increases the maximum of the elution profile and, therefore, enhances the dynamics of desorption significantly. The proposed dynamic model simulates experimental data satisfactorily at different temperatures.

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