



A lumped kinetic model for gold ore cyanidation

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Abstract

The effect of particle size on the kinetics of gold cyanidation was investigated for a gold ore from the Abitibi region (Canada). Six size fractions representative of the plant operation were used to carry out the gold leaching and cyanide consumption kinetic tests. A two-level factorial experimental design was used for the gold leaching tests of the six size fractions. The free cyanide concentrations were selected as 260 and 650 mg/L, the dissolved oxygen concentrations as 8 and 40 mg/L, and the pH was maintained constant at 12. The gold concentration as a function of time was fitted to a lumped pseudo-homogeneous kinetic model, using a least-squares method. The results show that the gold dissolution kinetic reaction orders are approximately two for gold, one for free cyanide and a quarter for dissolved oxygen, and that the kinetic rate constant is a decreasing cubic function of the ore particle average diameter. In the cyanide consumption tests, conducted also for the six different size fractions, the pH was maintained at 12, the dissolved oxygen concentration was chosen as 8 mg/L, and the initial free cyanide concentration as 260 mg/L. The cyanide consumption lumped kinetic model shows that the reaction order is approximately three for free cyanide, and that the rate constant is a decreasing reciprocal square-root function of the ore particle size. Although finer grind of the ore enhances gold release, it considerably increases the cyanide consumption due to the liberation of the copper and iron bearing minerals, thus leading to a possible optimization of the ore size fraction that can simultaneously promote high gold recovery and acceptable cyanide consumption.

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Keywords: Gold ore; Cyanidation; Kinetics; Leaching; Mathematical model; Cyanide consumption

1. Introduction

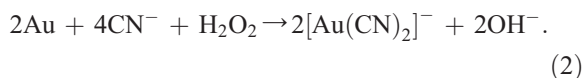
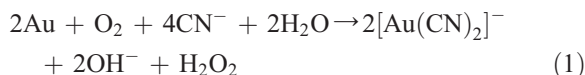
Leaching of ores by cyanide in aerated alkaline slurries has been the dominant process for gold ex-

traction for more than one century. Due to the economic relevance of this process its chemistry has been extensively investigated (Habashi, 1967; Habashi, 1987; Marsden and House, 1992). It is widely accepted that the pure gold cyanidation is an electrochemical process, where gold is oxidized and then complexed to the stable complex ion $[\text{Au}(\text{CN})_2]^-$, oxygen is reduced and hydrogen peroxide decomposed, leading to the following overall reactions (Kudryk and Kellogg, 1954; Habashi, 1967; Nicol

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(L.R.P. de Andrade Lima).

et al., 1987; Guzman et al., 1999; Jeffrey and Ritchie, 2001):



Kinetic studies of pure gold leaching have received a lot of attention, because they could result in effective improvements at industrial scale, such as the reduction of the operational cost or the optimization of the plant design. However, the gold ore cyanidation is a more complex system due to the fact that the gold particles occur as alloys or compounds that are embedded in a mineral matrix and galvanic interactions can take place between the phases. A feasible approach to model this system is based in the use of empirical rate equations that assume lumped reactions and lumped concentration of all gold species in the ore. This is a current approach in process engineering (Lee, 1985).

In this work, only the most relevant quantitative models available for pure gold and gold ore cyanidation will be presented. Initially the mechanistic models for pure gold will be briefly reviewed and then the empirical models will be discussed.

Habashi (1966, 1967) presented the following gold dissolution rate equation based on the electrochemical mechanism:

$$-r_{\text{Au}} = \frac{[\text{CN}^-][\text{O}_2]}{k_{\text{CN}^-}[\text{CN}^-] + k_{\text{O}_2}[\text{O}_2]} \quad (3)$$

where $r_{\text{Au}} = d[\text{Au}]_s/dt$ is the gold dissolution rate, $[\text{CN}^-]$ and $[\text{O}_2]$ are respectively the free cyanide and dissolved oxygen concentrations in the liquid phase, and k_{O_2} and k_{CN^-} the rate constants that depend upon gold surface area, oxygen and cyanide diffusivities, and boundary layer thickness. Rubisov et al. (1996) using data from gold ore cyanidation (Ling et al., 1996) fit a model for pure gold cyanidation based on Eq. (3) and the electrochemical model proposed by Wadsworth (1991) and Li et al. (1992); the authors suggested a three and a four parameter models with variable reaction order. Recently, Crundwell and Godorr (1997) proposed a model that accounts for the

leaching electrochemical mechanisms, gold surface passivation, and gold particle shrinkage. More recently, Wadsworth et al. (2000) proposed a gold cyanidation mechanistic model in which the gold dissolution is kinetically controlled by surface reactions, and the dissolution rate expressed as:

$$-r_{\text{Au}} = \frac{k_1[\text{CN}^-]^3}{1 + k_2[\text{CN}^-]^3} \quad (4)$$

where k_1 and k_2 are rate constants.

As mentioned above, the fundamental approach used to develop kinetic equations of gold cyanidation can help the comprehension of the chemical and physical phenomena that take place during this process; however, it has limited applicability to the description of gold ore cyanidation. This limitation is especially critical for process engineering applications, such as leaching reactor design and scale up, operation analysis, control, and optimization.

Process analysis of industrial systems using empirical kinetic models has been used for a long time in the chemical, petrochemical, biochemical, and metallurgical industries. Heterogeneous rate equations, where the resistances to mass transfer are taken into account, have been successfully used to describe many hydrometallurgical systems, especially when the reactive species are randomly distributed in an inert matrix of relatively low porosity.

In contrast with the heterogeneous models, the pseudo-homogeneous model, used in this study, assumes that the resistances to mass transfer are negligible and that the overall rate equation is identical to the intrinsic rate equation (Froment and Bischoff, 1990). This empirical approach has shown applicability in heterogeneous catalysis and many other processes. In the case of gold ore cyanidation, the pseudo homogeneous model likely holds for finer ground ores where a large number of gold particles are accessible to the reactants and the mass transfer resistances are negligible. Some previous studies using this approach are discussed next.

Brittan (1975) proposed the following equation based in the pseudo-homogeneous model to describe the gold ore cyanidation kinetics at room temperature,

$$-r_{\text{Au}} = k \left([\text{Au}]_s - [\text{Au}]_{s,\infty} \right) \quad (5)$$

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