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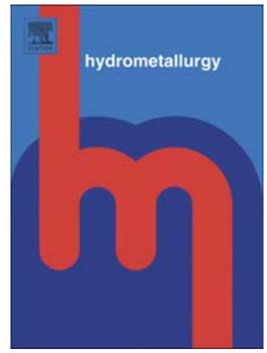

Models for apparent reaction kinetics in heap leaching: A new semi-empirical approach and its comparison to shrinking core and other particle-scale models

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Models for apparent reaction kinetics in heap leaching: a new semi-empirical approach and its comparison to shrinking core and other particle-scale models

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Abstract

Particle-scale effects are critically important to the performance of heap leaching operations. In a heap-scale simulation, the transport of fluid phases and reactive species external to the ore particles might be modelled with thousands of grid elements by the finite volume or finite element method. The inter- and intra-particle diffusions and reactions are usually parametrised by a deterministic model, such as the shrinking core model (SCM), that translates the external conditions into an effective product extraction rate. However, the rate equation takes the form of an implicit or partial differential equation for all but the simplest models and kinetic regimes, becoming expensive to solve on large grids. We instead propose an economical, easily calibrated semi-empirical approach in which the dependencies on external conditions and the current state of the ore are considered to be mathematically separable. We show that the standard SCM does not suffer greatly from this approximation even when there is a mixed control regime with nonlinear kinetics. The dependency on the state of the ore is derived empirically, inherently capturing heterogeneous features and cluster-scale effects. We demonstrate that this method scales correctly when fitted to data from physical column leaching experiments.

1 Introduction

Heap leaching is simple means of extracting valuable metals from low grade ore. With relatively low capital and operational costs, it has become increasingly popular in the mining industry. However, the design of heap leaching operations is far from optimal. Predictive models are needed, of which Bartlett (1992) defines two types: empirical and deterministic. Empirical models rely on historical data to parametrise a particular heap. These are valid provided there is enough data covering a large enough parameter space. Unfortunately, factors such as the properties of the ore mean that successful empirical models are likely to be site-specific at best. With so many variables involved in heap leaching operations, and comparatively little historical data available, scaling up the models to larger heaps is unfeasible and the cost on a per-installation basis remains high (Dixon, 2000).

In the absence of effective industrial empirical models, the research community has proposed various *deterministic* models for heap leaching systems. Deterministic models are created from first principles using what are believed to be the dominant physicochemical factors of the problem. However, the complete heap leaching system is complex and multiscale, with many interacting mechanisms at work. This makes the modelling of the system a challenging proposition. Some of the processes that are important include the transport of fluid through the packed bed, the mass transport within the ore particles and reactions such as the dissolution of metals and other species taking place at the mineral grain surfaces. The prediction of the behaviour of these systems is often complicated by the further interactions with processes such as biological activity, gas motion and heat transport. Heap leaching models that capture these processes have been developed by, for instance, Dixon (2000) and Leahy et al. (2006).

The transport processes and chemical reactions occurring within the ore particle are modelled together, with the mineral grains assumed to be dispersed evenly throughout the ore such that the entire solid may be considered to act as a homogeneous reactant. The emergent rate of conversion is dependent upon the current state of the leaching and the concentration of the reagents in the fluid surrounding the ore particle. This intra-particle modelling is usually done by means of the shrinking core model (SCM) or one of its variants. In the standard SCM (Yagi and Kunii, 1955), each particle is assumed to be a sphere of initially unreacted material. Reaction takes place on the surface of the sphere and then progresses inwards, such that the core of unreacted material shrinks and leaves behind a layer of inert, permeable, solid product. This situation is representative of leaching when there is a thin reaction zone (Braun et al., 1974; Roman et al., 1974). Under further assumptions an explicit ordinary differential equation (ODE) can be formed from which the product extraction rate may be calculated straightforwardly, otherwise an implicit and/or partial differential equation must be resolved.