metals

Editorial
Leaching Kinetics of Valuable Metals

Stefano Ubaldini

Istituto di Geologia Ambientale e Geoingegneria, CNR, Area della Ricerca di Roma RM 1—Montelibretti—Via Salaria Km 29,300, Monterotondo, 00015 Roma, Italy; stefano.ubaldini@igag.cnr.it; Tel.: +39-06-90672748

Citation: Ubaldini, S. Leaching Kinetics of Valuable Metals. *Metals* **2021**, *11*, 173. https://doi.org/10.3390/met11010173

Received: 18 January 2021
Accepted: 18 January 2021
Published: 19 January 2021

1. Introduction and Scope

Leaching is a primary extractive operation in hydrometallurgical processing, by which a metal of interest is transferred from naturally-occurring minerals into an aqueous solution. In essence, it involves the selective dissolution of valuable minerals, where the ore, concentrate, or matte is brought into contact with an active chemical solution known as a leach solution.

There are numerous hydrometallurgical process technologies used for recovering metals, such as: agglomeration; leaching; solvent extraction/ion exchange; metal recovery; and remediation of tailings/waste. Currently, hydrometallurgical processes have a wide range of useful applications, not only in the mining sector—in particular, for the recovery of precious metals, such as gold and silver—but also in the environmental sector, for the recovery of toxic metals (such as copper, nickel, zinc, manganese, arsenic, cadmium, chromium, lead) from wastes of various types, and their reuse as valuable metals, after purification.

Therefore, there is an increasing need to develop novel solutions, to implement environmentally sustainable practices in the recovery of these valuable and precious metals, with particular reference to the critical metals, that are those included in materials that are indispensable to modern life and for which an exponential increase in consumption is already a reality or will be in a short-term perspective (antimony, indium, vanadium, rare hearts, etc.). Consequently, the economics of the processes, which are closely linked to the kinetics of leaching, are of great importance.

For publication in this Special Issue, consideration has been given to articles that contribute to the optimization of the kinetic conditions of innovative hydrometallurgical processes—economic and of low environmental impact—applied for the recovery of valuable and critical metals.

I would like to thank the authors who accepted this invitation, helping us to produce a high-impact, high-quality Special Issue on the "Leaching Kinetics of Valuable Metals".

2. Contributions

Researchers around the globe investigating the leaching kinetics of valuable metals have been invited to submit research papers, so that readers can recognize the common points between them. Among the submitted manuscripts, eleven articles have been published in the issue.

The papers are all of high scientific value, while the experimental activities carried out fall into various disciplinary sectors, confirming the importance of the studies of the leaching kinetics of valuable metals in different scientific and technological fields. Here, I will briefly summarize the content of the published papers.

Geochemical characterization studies and batch leaching experiments were conducted to explore the effects of a $CO_2 + O_2$ leaching system on uranium (U) recovery from ores obtained from an eastern limb of the Zinda Pir Anticline ore deposit in Pakistan [1]. This study provides new insights into the feasibility and validity of the site application of U neutral in situ leaching. According to Asghar F. et al., further studies are needed to reveal the influencing mechanism of the U(VI) initial concentration on U recovery in the solid phase.

While considerable experimental material has accumulated on the purification of uranium-containing water using nanoscale zero-valent iron (nZVI), there are no comparative studies of the sorption properties of iron-containing composites of different composition based on clay minerals. Taking into account the importance of environmental studies based on natural minerals, the removal of uranium by nZVI supported on kaolinite, montmorillonite and palygorskite was investigated by Kornilovych et al., including the removal efficiency of uranium from contaminated groundwater with low and high mineralization [2].

The kinetics of dissolution of refractory sulfide gold-containing concentrates of the Yenisei ridge (Yakutia, Russia) by a solution of HNO_3 in the temperature range of 70–85 °C was investigated by Rogozhnikov et al., leading to the conclusion that the increase in sulfur content in concentrate can be used to ensure the more energy-efficient oxidation of sulfide minerals [3].

A physical–chemical activation desilication process was proposed to extract silica from high alumina fly ash (HAFA) [4]. The effects of fly ash size, hydrochloric acid concentration, acid activation time and reaction temperature on the desilication efficiency, were investigated comprehensively. The results achieved by Gong et al. indicate that physical and chemical activation suppresses the formation of zeolite, thereby improving the desilication efficiency and further improving the A/S of the fly ash; results which are very advantageous for the next step of alumina extraction.

A study of the oxidation of thiosulfate, with oxygen using copper (II) as a catalyst, at a pH between 4 and 5 has been conducted by González-Lara et al. [5]. The basic idea was to avoid the formation of tetrathionate and polythionate, transforming the thiosulfate into sulfate. The nature of the reaction and a kinetic study of thiosulfate transformation, by reaction with oxygen and Cu^{2+} at a ppm level, have been determined and reported. The thiosulfate concentration was reduced from 1 $g \cdot L^{-1}$ to less than 20 ppm in less than three hours.

The paper by Batnasan et al. [6] deals with the recovery of gold from waste printed circuit boards (WPCBs) ash by high-pressure oxidative leaching (HPOL) pre-treatment and iodide leaching followed by reduction precipitation. Under the optimal conditions, the percentage of gold extraction from the gold chips and the residue of WPCBs was 99% and 95%, respectively.

The objective of the experimental work carried out by Ubaldini et al. is the application of innovative and sustainable technologies for the treatment and exploitation of mining tailings from Romania [7]. The results obtained by application of the thiosulfate process on a low gold content ore were considered encouraging. The optimization of process parameters and operating conditions should permit the best results in terms of process yields to be achieved.

In the article submitted by Cháidez et al., a copper leaching process from chalcopyrite concentrates using a low-pressure reactor is presented. The experimental results showed that it is possible to extract 98% of copper in only 3 h. This result indicates a fast process compared with others reported in the literature [8].

The experimental results obtained during the preparation of Al-Ni and Al-Ni-Mg alloys using the aluminothermic reduction of NiO by submerged powder injection, assisted with mechanical agitation, are presented and discussed by Silva Beltran et al. [9].

Zhovty Vody city, located in south-central Ukraine, has long been an important center for the Ukrainian uranium and iron industries. Uranium and iron mining and processing activities during the Cold War resulted in poorly managed sources of radionuclides and heavy metals. Widespread groundwater and surface water contamination has occurred, which creates a significant risk to drinking water supplies [10]. The results of the study conducted by Kornilovych et al. demonstrate the effectiveness of the use of the permeable reactive barrier (PRB) for ground water protection near uranium mine tailings storage facility (TSF). The greatest decrease was obtained using zero-valent iron (ZVI)-based reactive media and the combined media of ZVI/phosphate/organic carbon combinations.

Eudialyte is a promising mineral for rare earth elements (REE) extraction due to its good solubility in acid, low radioactivity, and relatively high content of REE. Ma et al. present a study assessing the two stage hydrometallurgical treatment of eudialyte concentrate: dry digestion with hydrochloric acid and leaching with water. The research reported in this paper [11], also as a novelty, explored the feasibility and efficiency of the REE extraction process at room temperature on a scale-up demonstration platform that precedes future industrial applications. Information on upscaling operations for the treatment of eudialyte is also missing in the overall literature.

3. Conclusions and Outlook

A variety of topics have composed this Special Issue, presenting recent developments within the field of leaching kinetics of valuable metals.

As Guest Editor, I am very happy for the success of this Special Issue. I am also proud of the final result, in addition to the high quality and originality of the contributions. I hope that all the scientific results in this Special Issue contribute to the advancement and future development of research in this field.

I would like to warmly thank all the authors for their contributions, and all the reviewers for their efforts in ensuring a high-quality publication. Sincere thanks also to the Editors of *Metals* for their continuous help, and to the *Metals* Editorial Assistants for the valuable and inexhaustible engagement and support during the preparation of this volume. In particular, my sincere thanks to Mr. Toliver Guo for his help and support.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Asghar, F.; Sun, Z.; Chen, G.; Zhou, Y.; Li, G.; Liu, H.; Zhao, K. Geochemical Characteristics and Uranium Neutral Leaching through a CO_2 + O_2 System—An Example from Uranium Ore of the ELZPA Ore Deposit in Pakistan. *Metals* **2020**, *10*, 1616. [CrossRef]
2. Kornilovych, B.; Kovalchuk, I.; Tobilko, V.; Ubaldini, S. Uranium Removal from Groundwater and Wastewater Using Clay-Supported Nanoscale Zero-Valent Iron. *Metals* **2020**, *10*, 1421. [CrossRef]
3. Rogozhnikov, D.A.; Shoppert, A.A.; Dizer, O.A.; Karimov, K.A.; Rusalev, R.E. Leaching Kinetics of Sulfides from Refractory Gold Concentrates by Nitric Acid. *Metals* **2019**, *9*, 465. [CrossRef]
4. Gong, Y.; Sun, J.; Sun, S.-Y.; Lu, G.; Zhang, T.-A. Enhanced Desilication of High Alumina Fly Ash by Combining Physical and Chemical Activation. *Metals* **2019**, *9*, 411. [CrossRef]
5. González Lara, J.M.; Cardona, F.P.; Vallmajor, A.R.; Cadevall, M.C. Oxidation of Thiosulfate with Oxygen Using Copper (II) as a Catalyst. *Metals* **2019**, *9*, 387. [CrossRef]
6. Batnasan, A.; Haga, K.; Huang, H.-H.; Shibayama, A. High-Pressure Oxidative Leaching and Iodide Leaching Followed by Selective Precipitation for Recovery of Base and Precious Metals from Waste Printed Circuit Boards Ash. *Metals* **2019**, *9*, 363. [CrossRef]
7. Ubaldini, S.; Guglietta, D.; Vegliò, F.; Giuliano, V. Valorization of Mining Waste by Application of Innovative Thiosulphate Leaching for Gold Recovery. *Metals* **2019**, *9*, 274. [CrossRef]
8. Cháidez, J.; Parga, J.; Valenzuela, J.; Carrillo, R.; Almaguer, I. Leaching Chalcopyrite Concentrate with Oxygen and Sulfuric Acid Using a Low-Pressure Reactor. *Metals* **2019**, *9*, 189. [CrossRef]
9. Beltran, C.S.; Valdes, A.F.; Torres, J.T.; Palacios, R.O. A Kinetic Study on the Preparation of AlNi Alloys by Aluminothermic Reduction of NiO Powders. *Metals* **2018**, *8*, 675. [CrossRef]
10. Kornilovych, B.; Wireman, M.; Ubaldini, S.; Guglietta, D.; Koshik, Y.; Caruso, B.; Kovalchuk, I. Uranium Removal from Groundwater by Permeable Reactive Barrier with Zero-Valent Iron and Organic Carbon Mixtures: Laboratory and Field Studies. *Metals* **2018**, *8*, 408. [CrossRef]
11. Ma, Y.; Stopic, S.; Gronen, L.; Milivojevic, M.; Obradovic, S.; Friedrich, B. Neural Network Modeling for the Extraction of Rare Earth Elements from Eudialyte Concentrate by Dry Digestion and Leaching. *Metals* **2018**, *8*, 267. [CrossRef]