

Editorial

# Editorial on Special Issue “Surface Chemistry in Mineral Processing and Extractive Metallurgy”

Hyunjung Kim <sup>1,\*</sup> , Hongbo Zhao <sup>2</sup> and Sadia Ilyas <sup>3</sup>

<sup>1</sup> Department of Mineral Resources and Energy Engineering, Jeonbuk National University, 567, Baekje-daero, Deokjin-gu, Jeonju, Jeonbuk 54896, Korea

<sup>2</sup> School of Minerals Processing & Bioengineering, Central South University, Changsha 410083, China; zhbalexander@csu.edu.cn

<sup>3</sup> Mineral and Material Chemistry Laboratory, Department of Chemistry, University of Agriculture, Faisalabad 38040, Pakistan; sadiailyas1@yahoo.com

\* Correspondence: kshjkim@jbnu.ac.kr

## 1. Introduction

“Mineral Processing” and “Extractive Metallurgy” are the key operations for the entire mining, metallurgy, and chemical industries. In both operations, reactions occur onto the surface interface. In particular, the rate-determining steps for a high throughput of mineral beneficiation and efficiency of (bio)hydrometallurgical processes are controlled by the interfacial reactions onto the mineral’s surfaces [1]. In order to liberate the metals of economic interest or reject the impurities, the efficiency of conventional mineral beneficiation techniques is usually low while feeding <20 μm particles [2]. The properties of such fine particles cannot be controlled by bulk properties albeit they depend on the surface properties of the particles [3]. Such particles in suspension may collide with each other due to the Brownian motion, and the suspension can be maintained at a stable level in the case of a high potential barrier. Furthermore, by chemically controlling the surface potentials, it is possible to achieve a wide range of their coagulation rates. For example, at a pH of around 7.5, the hematite particles can be coagulated selectively with one another but they differ from quartz particles. In addition, under these conditions, quartz particles do not coagulate appreciably with each other. Thus, the separation between two mineral phases can be achieved by yielding a high enrichment of hematite.

It is widely accepted that at a known concentration of potential-determining ions, a negative or positive charge can be created at a solid and/or, solution interface. For silicates and oxides minerals, proton (H<sup>+</sup>) and hydroxyl (OH<sup>-</sup>) ions are shown to be potential-determining ions [2]. Different electrical charges created on mineral surfaces at a particular pH can be exploited in the electrophoresis to separate the mixtures of fine minerals’ particles. Moreover, the Derjaguin–Landau–Verwey–Overbeek (DLVO) theory of colloid stability states that the repulsive forces arising from the presence of electrical double layers keep the particles apart in a stable lyophobic colloid [4]. Aggregation of particles can be achieved either via the charge neutralization that manifests in bringing to light the van der Waals forces or through the addition of a polyelectrolyte that aggregates the particles via a “bridging mechanism” usually termed as flocculation. In this mechanism, the finely divided solids can be agglomerated in a liquid by adding a small amount of second liquid that is immiscible with the first liquid and preferentially wets the solid particles. With a critical amount of bridging liquid and suitable agitation, the solids can be separated as highly spherical bodies; hence, the process is known as “spherical agglomeration”.

Flotation is an important widely used beneficiation process [5], particularly for separating metal sulfides from undesired ones and gangue materials [6–8]. An aqueous suspension of a finely ground ore is conditioned with flotation chemicals by changing the surface properties as per the requirements by making the metal sulfides either more hydrophobic



**Citation:** Kim, H.; Zhao, H.; Ilyas, S. Editorial on Special Issue “Surface Chemistry in Mineral Processing and Extractive Metallurgy”. *Minerals* **2021**, *11*, 13. <https://dx.doi.org/10.3390/min11010013>

Received: 16 December 2020

Accepted: 21 December 2020

Published: 25 December 2020

**Publisher’s Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

(collector) or more hydrophilic (depressant) [9,10]. In the case of collectors, small air bubbles are produced to aggregate with the hydrophobic particles, making them float on the suspension with froth [11,12]. In the case of depressants, hydrophilic sulfides are depressed to be kept in the liquid solution [13]. It is a very useful method in mineral beneficiation albeit harmful to the environment due to the associated toxicity with the frequently used depressants like  $\text{SO}_2$ , chromate, and cyanide compounds; hence,  $\text{SiO}_2$  is used as a potential depressant in scheelite flotation [14]. Consequently, the use of microbial activity in the floatation process has been designed wherein the sulfur- and/or iron-oxidizing bacteria are employed to oxidize the metal sulfides. The bacteria selectively attach to sulfide surfaces (their substrate), forming a biofilm layer onto the bacterial cells plus excreted extracellular polymeric substances (EPS) that consists of polysaccharides, lipids, and sometimes includes proteins and nucleic acids as well [15,16]. The bacterial attachment to sulfide mineral alters the particle to become more hydrophilic, exhibiting biofloatation. Nevertheless, the know-how on the selectivity of bacterial species to sulfide minerals is limited. In the future, more studies will be conducted on free EPS and related compounds with the objective of replacing the toxic depressing chemicals with EPS-derived reagents from microorganisms that can alter the mineral surfaces.

The biofloatation followed by the bacterial leaching for metal extraction that replaces the use of a large amount of toxic and hazardous chemicals is considered as a future technology in terms of sustainable processes. Bioleaching takes place at the interface of bacteria, metal sulfide, and metabolic produced lixivants that dissolve metals in their ionic species [17]. Fundamental forces between bioleaching bacterium and mineral surfaces are the central point to understand the intricacies of interfacial phenomenon, like bacterial adhesion or metal detachment from mineral surface followed by dissolution of metal in ionic form [15]. More precisely, it uses a catalytic effect produced by metabolic activity of the microorganisms [18]. On the other side, the adhesion behavior of a bacterial cell surface in the aqueous environment is mediated by various physicochemical intersections including van der Waals forces, electrostatic interaction, steric forces, hydration, and hydrophobic interactions [19].

Given that there are knowledge gaps in the aforementioned contexts, a deep study on surface chemistry that includes the solid–liquid, solid–gas, mineral-to-microbe interfaces, aiming towards modifying the chemical properties/composition [20] of a mineral surface by incorporation of the selected elements/functional groups, is vitally imperative. Therefore, the present issue on the “Surface Chemistry in Mineral Processing and Extractive Metallurgy” gives an insight into the focused area of study. The issue comprises 15 articles on various aspects and dealing with different types of feed minerals/materials using the (bio)floatation, (bio)hydrometallurgy, surface characterization, adsorption, and corrosion techniques.

This Special Issue contains: (i) the purification of high As(III) wastewater by a synergistic treatment with red mud and  $\text{Fe}^{3+}$  ions forming the ferric arsenite on the surface of red mud; (ii) bioinformatics and transcriptional study of the natural resistance-associated macrophage protein function in ferrous ion transport into the cells; (iii) the role of ammonium ions in the sulfidization, xanthate-flotation of malachite; (iv) the leaching kinetics of weathered crust elution-deposited rare earth ore with compound ammonium carboxylate; (v) the study of temperature's effect on the xanthate's performance during chalcopyrite flotation; (vi) the pore connectivity and dewatering mechanism of tailings bed in ranking deep-cone thickener processes; (vii) improved understanding of the sulfidization mechanism in amine flotation of smithsonite using XPS, AFM, and UV-Vis DRS studies; (viii) the mechanism for the bio-oxidation and decomposition of pentlandite: implications for nickel bioleaching at elevated pH; (ix) bastnaesite, barite, and calcite flotation behaviors with salicylhydroxamic acid as the collector; (x) the effect of  $\text{Cu}^{2+}$  on the activation to muscovite using electrochemical pretreatment; (xi) the performance and adsorption mechanism of a novel collector, dodecyl dimethyl betaine (BS-12), for the floatation separation of ilmenite and titanite; (xii) insight into the influence of surface roughness on the wettability of

apatite and dolomite; (xiii) utilization of sodium hexametaphosphate for separating scheelite from calcite and fluorite using an anionic-nonionic collector; (xiv) The contribution of long-terms static interactions between minerals and flotation reagents for the separation of fluorite and calcite; and (xiv) the role of colloidal silica as a depressant in scheelite flotation.

We thank the Editor-in-chief Prof. (Dr.) Paul Sylvester for allowing the commissioning of this Special Issue and extend our thanks to all the contributing authors for submission of their valuable piece of work and maintaining cooperation in terms of timely publication of the issue.

## References

1. He, D.; Xiong, Y.; Wang, L.; Sun, W.; Liu, R.; Yue, T. Arsenic (III) removal from a high-concentration arsenic (III) solution by forming ferric arsenite on red mud surface. *Minerals* **2020**, *10*, 583. [[CrossRef](#)]
2. Laskowski, J. Interfacial chemistry of mineral processing separations. In *Surface and Colloid Science*; Matijević, E., Ed.; Springer: Boston, MA, USA, 1982; Volume 12. [[CrossRef](#)]
3. Solongo, S.K.; Gomez-Flores, A.; You, J.; Choi, S.; Heyes, G.W.; Ilyas, S.; Lee, J.; Kim, H. Cationic collector conformations on an oxide mineral interface: Roles of pH, ionic strength, and ion valence. *Miner. Eng.* **2020**, *150*, 106277. [[CrossRef](#)]
4. Gomez-Flores, A.; Solongo, S.K.; Heyes, G.W.; Ilyas, S.; Kim, H. Bubble–particle interactions with hydrodynamics, XDLVO theory, and surface roughness for flotation in an agitated tank using CFD simulations. *Miner. Eng.* **2020**, *152*, 106368. [[CrossRef](#)]
5. Huang, L.; Zeng, Q.; Hu, L.; Hu, Y.; Zhong, H.; He, Z. The contribution of long-terms static interactions between minerals and flotation reagents for the separation of fluorite and calcite. *Minerals* **2020**, *9*, 699. [[CrossRef](#)]
6. Liu, R.; Liu, Z.; Li, J.; Ao, S.; Pei, B.; Liu, D.; Li, J. Reexamining the role of ammonium ions in the sulfidization, xanthate-flotation of malachite. *Minerals* **2020**, *10*, 537. [[CrossRef](#)]
7. An, D.; Zhang, J. A study of temperature effect on the xanthate’s performance during chalcopyrite flotation. *Minerals* **2020**, *10*, 426. [[CrossRef](#)]
8. Wang, Y.; Wang, Y.; Xiao, W.; Wei, Y.; Li, S. Effect of Cu<sup>2+</sup> on the activation to muscovite using electrochemical pretreatment. *Minerals* **2020**, *10*, 206. [[CrossRef](#)]
9. Liu, R.; Pei, B.; Liu, Z.; Wang, Y.; Li, J.; Liu, D. Improved Understanding of the Sulfidization Mechanism in Amine Flotation of Smithsonite: An XPS, AFM and UV–Vis DRS Study. *Minerals* **2020**, *10*, 370. [[CrossRef](#)]
10. Wang, X.; Zhang, Q. Insight into the influence of surface roughness on the wettability of apatite and dolomite. *Minerals* **2020**, *10*, 114. [[CrossRef](#)]
11. Chen, P.; Chai, X.; Tian, M.; Chen, W.; Wan, S.; Meng, Q.; Zhai, J.; Gao, Y. The performance and adsorption mechanism of a novel collector, dodecyl dimethyl betaine (BS-12), for the flotation separation of ilmenite and titanite. *Minerals* **2020**, *10*, 116. [[CrossRef](#)]
12. Kang, J.; Hu, Y.; Sun, W.; Gao, Z.; Liu, R. Utilization of sodium hexametaphosphate for separating scheelite from calcite and fluorite using an anionic–nonionic collector. *Minerals* **2020**, *9*, 705. [[CrossRef](#)]
13. Xiong, W.; Deng, J.; Zhao, K.; Wang, W.; Wang, Y.; Wei, D. Bastnaesite, barite, and calcite flotation behaviors with salicylhydroxamic acid as the collector. *Minerals* **2020**, *10*, 282. [[CrossRef](#)]
14. Kupka, N.; Babel, B.; Rudolph, M. The Potential Role of Colloidal Silica as a Depressant in Scheelite Flotation. *Minerals* **2020**, *10*, 144. [[CrossRef](#)]
15. You, J.; Solongo, S.K.; Gomez-Flores, A.; Choi, S.; Zhao, H.; Urik, M.; Ilyas, S.; Kim, H. Intensified bioleaching of chalcopyrite concentrate using adapted mesophilic culture in continuous stirred tank reactors. *Bioresour. Technol.* **2020**, *307*, 123181. [[CrossRef](#)] [[PubMed](#)]
16. Srivastava, R.R.; Ilyas, S.; Kim, H.; Choi, S.; Trinh, H.B.; Ghauri, M.A.; Ilyas, N. Biotechnological recycling of critical metals from waste printed circuit boards. *J. Chem. Technol. Biotechnol.* **2020**, *95*, 2796–2810. [[CrossRef](#)]
17. Chai, X.; Li, G.; Zhang, Z.; Chi, R.; Chen, Z. Leaching kinetics of weathered crust elution-deposited rare earth ore with compound ammonium carboxylate. *Minerals* **2020**, *10*, 516. [[CrossRef](#)]
18. Sun, J.; Wen, J.; Wu, B.; Chen, B. Mechanism for the bio-oxidation and decomposition of pentlandite: Implication for nickel bioleaching at elevated pH. *Minerals* **2020**, *10*, 289. [[CrossRef](#)]
19. Miao, B.; Shen, L.; Liu, X.; Zeng, W.; Wu, X. Bioinformatics and transcriptional study of the Nramp Gene in the extreme acidophile *Acidithiobacillus ferrooxidans* strain DC. *Minerals* **2020**, *10*, 554. [[CrossRef](#)]
20. Chen, X.; Jin, X.; Jiao, H.; Yang, Y.; Liu, J. Pore connectivity and dewatering mechanism of tailings bed in raking deep-cone thickener process. *Minerals* **2020**, *10*, 375. [[CrossRef](#)]