Preparation of Mineral Silica-Potash Fertilizer from Calcified-Potash Alkaline Treated Red Mud

Qingdong Li[1], Guozhi Lv[2], Zhuangzhuang Yun[3], Zhihui Gu[4], Fangyi Yuan[5] and Tingan Zhang[6]
1, 3, 4, 5. PhD student
2, 6. Professor
Northeastern University - Laboratory of Ecological Metallurgy of Multi-metal Intergrown Ores of Ministry of Education, Shenyang, China
Corresponding e-mail: lvgz@smm.neu.edu.cn
https://doi.org/10.71659/icsoba2025-br020

Abstract

As a significant bulk solid waste, the emission and accumulation of red mud have been increasing annually, severely damaging the ecological environment and posing safety hazards. With the growing scarcity of high-quality aluminum resources, red mud has gradually attracted attention due to its richness in various valuable metals such as aluminum (Al) and iron (Fe). In response to the challenges posed by the scale of Bayer red mud disposal and the potassium deficiency in China's soil, the Northeastern University Special Metallurgy Innovation Team has proposed a novel process for preparing mineral silica-potassium fertilizer through a one-step hydrothermal leaching of red mud within a calcareous-potassium alkali system. This process involves leaching red mud with potassium hydroxide (KOH), which not only extracts alumina but also replaces the harmful sodium element in red mud. Consequently, hydrated sodium silicoaluminate in red mud is transformed into potassium silicoaluminate. The resulting transformed slag can be utilized to produce mineral silica-potassium fertilizer, thereby promoting crop growth. This paper aims to achieve sustainable red mud production through KOH hydrothermal leaching by investigating the effects of mixed solutions with varying sodium and potassium ratios on the preparation of silica-potassium mineral fertilizers, facilitating synergistic sodium removal and aluminum extraction. This research provides a new reference for the realization of cross-boundary resource recycling in the context of "Aluminum-Agriculture," addressing the issues of red mud accumulation and alleviating the pressure on the scarcity of aluminum resources and potash fertilizers, thereby enhancing the core competitiveness of China's alumina enterprises.

Keywords: Red mud, Hydrothermal leaching, Total quantitative elimination, Mineral silica-potash fertilizer.

1. Introduction

Currently, the industrial production of alumina predominantly uses the Bayer method and the sintering method, as illustrated in Figure 1 below. The Bayer method is optimal for high-grade bauxite ores with an Al_2O_3/SiO_2 ratio ranging from 7 to 10, whereas the sintering process is applicable to bauxite ores with an Al_2O_3/SiO_2 ratio between 3 and 6. Notably, the energy consumption of the sintering process is significantly higher, requiring approximately 30 GJ to produce one tonne of alumina, which is 2.5 times greater than that of the Bayer process [1]. Furthermore, the Bayer method accounts for over 90 % of global alumina production [2]. In 2022, China's alumina production capacity exceeded 99.5 million tonnes, with an actual output reaching

79.76 million tonnes, representing 58.2 % of the total global output, thereby establishing it as a pillar industry within China's metallurgical sector.

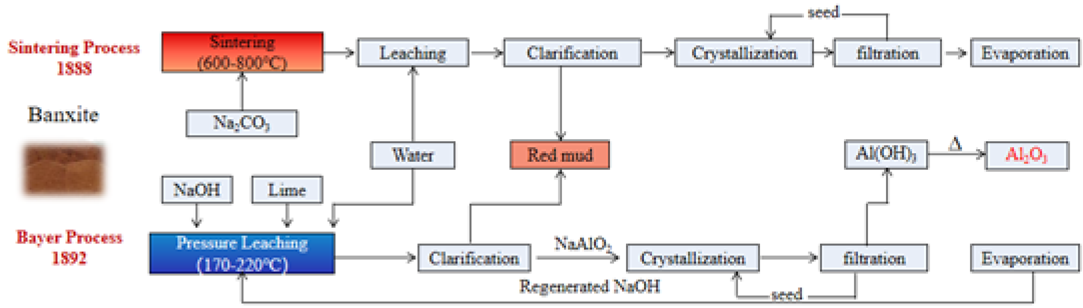

Figure 1. Bayer's and sintering process flow sheet [1].

The production of 1 tonne of alumina via the Bayer method generates between 0.6 and 2.0 tonnes of red mud, resulting in a global stockpile of red mud that has surpassed 5 billion tonnes and continues to increase at an alarming rate of nearly 200 million tonnes per year. In China alone, the red mud stockpile has exceeded 1.2 billion tonnes [3]. Due to its complex composition, large specific surface area, and strong alkalinity, finding large-scale applications for red mud has proven to be challenging [4]. Current utilization of red mud can be categorized into several areas, as illustrated in Figure 2: (1) construction materials, including the preparation of cement, ceramics, or road base materials [5–7]; (2) metal recycling, focusing on the recovery of iron, titanium, aluminum, or rare earth elements [1, 8]; (3) the production of environmentally friendly chemical materials, such as modified adsorbents, desulfurizers, or molecular sieves [9]; and (4) agricultural applications, particularly in the formulation of soil conditioners. However, due to the high alkalinity of red mud and issues related to the stability of heavy metals, most of these processes remain in the experimental research phase. The global comprehensive utilization rate of bauxite slag is approximately 15 %, while in China, it is less than 5 %.

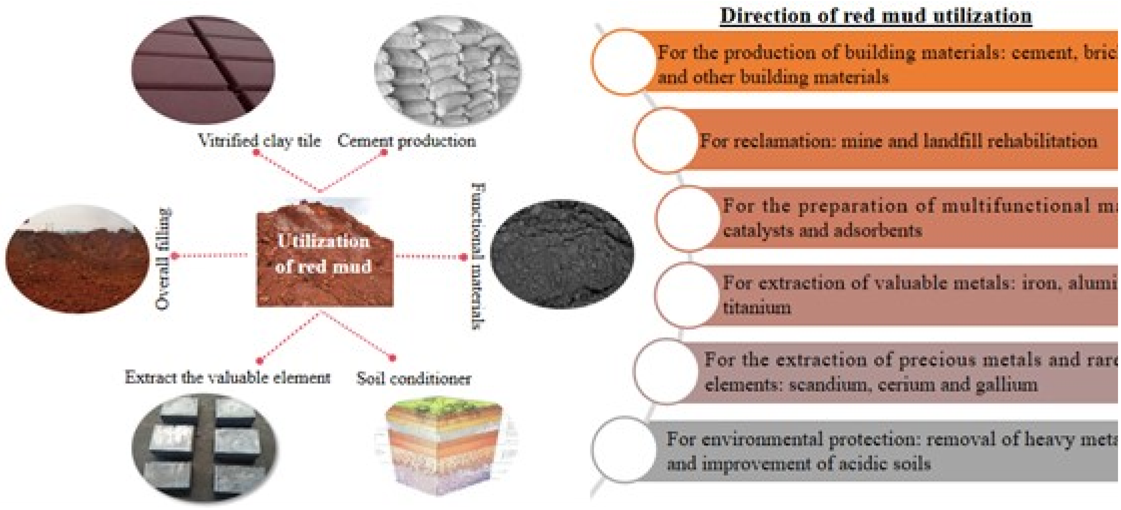

Figure 2. Summary of existing methods and routes for utilizing red mud.

Currently, the predominant method for treating red mud remains stacking and damming, which not only increases costs but also creates significant environmental safety hazards. Red mud pollutants have the potential to seep into both surface water and groundwater,

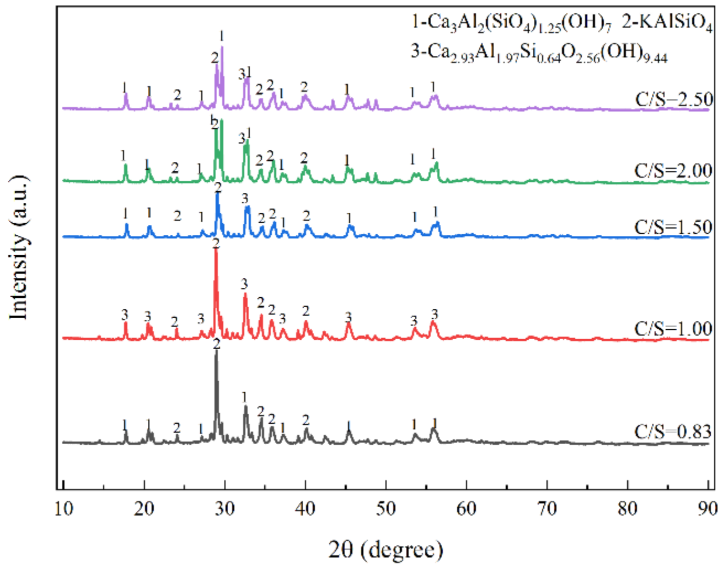

Figure 7. XRD results of transformation products with different Ca-Si ratios at Na_2O/K_2O molar ratio = 0.206.

4. Conclusion

To achieve sustainable production of silica-potassium mineral fertilizer through hydrothermal leaching of red mud with KOH, it is essential to recycle the leaching solution. This study investigates the impact of mixed solutions with varying sodium-potassium ratios on the synergistic desodiumization and alumina extraction from red mud for the preparation of silica-potassium mineral fertilizer. The findings indicate that sodium atoms in the slag phase of the hydrothermal leaching process are released into the KOH solution as Na^+, with the sodium content in the leachate being a critical factor affecting recycling efficiency. When the molar ratio of Na_2O to K_2O in the sodium-potassium mixed solution is 0.206, the mass fraction of Na_2O in the transformed slag obtained from hydrothermal leaching of red mud at 260 °C for 1 hour is 0.44 %. The primary equilibrium mineral phase of the product shifts from hydrated sodium silica-aluminate to potassium silica-aluminate and partially hydrated garnet, with Na_2O, K_2O, and SiO_2 contents recorded at 0.44 %, 11.86 %, and 22.26 %, respectively. Furthermore, the mineral-based silicon and potassium fertilizer can be enhanced with organic matter to meet plant growth requirements. This process does not produce secondary pollution, offering a novel reference scheme for addressing the red mud accumulation issue and promoting sustainable clean alumina production.

5. Acknowledgments

The authors gratefully acknowledge the financial support of this work by the National Natural Science Foundation of China (No. ZX20230386), the Cross-Integration and Collaborative Development Project of Northeastern University (No. N2225013), the 2023 Special Project for High-Industrial Base Reconstruction Quality Development of the Manufacturing Industry (No. 2023ZY01019–11), the Jiangxi Province "Double Thousand Plan" Project (No. S2021DQKJ2198), and the sixth batch of top talent support funds (No. QNBJ-2022-04).

6. References

1. Sandeep Agrawal and Nivedita Dhawan, Evaluation of red mud as a polymetallic source – a review, *Minerals Engineering*, 171, 2021, 107084. https://doi.org/10.1016/j.mineng.2021.107084.

2. Emmanuel Mukiza et al., Utilization of red mud in road base and subgrade materials: a review, *Resources, Conservation and Recycling*, 141, 2019, 187–199. https://doi.org/10.1016/j.resconrec.2018.10.031.
3. Qiang Li et al., Summary of research progress on the separation and extraction of iron from Bayer red mud, *Journal of Sustainable Metallurgy*, 2025. https://doi.org/10.1007/s40831-024-00986-0.
4. Guozhi Lu et al., Utilization of Bayer red mud by a calcification–carbonation method using calcium aluminate hydrate as a calcium source, *Hydrometallurgy*, 188, 2019, 248–255. https://doi.org/10.1016/j.hydromet.2019.05.018.
5. Goutam Bhattacharya et al., Recycled red mud–decorated porous 3D graphene for high-energy flexible micro-supercapacitor, *Advanced Sustainable Systems*, 4, 2020, 1900133. https://doi.org/10.1002/adsu.201900133.
6. Rui Chen et al., Mechanical properties and micro-mechanism of loess roadbed filling using by-product red mud as a partial alternative, *Construction and Building Materials*, 216, 2019, 188–201. https://doi.org/10.1016/j.conbuildmat.2019.04.254.
7. Saurabh Singh, M.U. Aswath, R.V. Ranganath, Performance assessment of bricks and prisms: red mud based geopolymer composite, *Journal of Building Engineering*, 32, 2020, 101462. https://doi.org/10.1016/j.jobe.2020.101462.
8. Milica Jovičević-Klug et al., Green steel from red mud through climate-neutral hydrogen plasma reduction, *Nature*, 625, 2024, 703–709. https://doi.org/10.1038/s41586-023-06901-z.
9. Yanan Du et al., Fabrication of a low-cost adsorbent supported zero-valent iron by using red mud for removing Pb(ii) and Cr(vi) from aqueous solutions, *RSC Advances*, 9, 2019, 33486–33496. https://doi.org/10.1039/c9ra06978j.
10. Claire L. Lockwood et al., Leaching of copper and nickel in soil-water systems contaminated by bauxite residue (red mud) from Ajka, Hungary: the importance of soil organic matter, *Environmental Science and Pollution Research*, 22, 2015, 10800–10810. https://doi.org/10.1007/s11356-015-4282-4.
11. Helio I. Gomes et al., Alkaline residues and the environment: a review of impacts, management practices and opportunities, *Journal of Cleaner Production*, 112, 2016, 3571–3582. https://doi.org/10.1016/j.jclepro.2015.09.111.
12. Ian T. Burke et al., Speciation of arsenic, chromium, and vanadium in red mud samples from the Ajka spill site, Hungary, *Environmental Science & Technology*, 46, 2012, 3085–3092. https://doi.org/10.1021/es3003475.
13. S.K. Jena et al., Investigation of microwave roasting for potash extraction from nepheline syenite, *Separation and Purification Technology*, 161, 2016, 104–111. https://doi.org/10.1016/j.seppur.2016.01.039.
14. M.J. Van Oosten et al., The role of biostimulants and bioeffectors as alleviators of abiotic stress in crop plants, *Chemical and Biological Technologies in Agriculture*, 4, 2017, 5. https://doi.org/10.1186/s40538-017-0089-5.
15. Jing Zhang et al., Characteristics and influencing factors of microbial community in heavy metal contaminated soil under silicon fertilizer and biochar remediation, *Adsorption Science & Technology*, 2021, https://doi.org/10.1155/2021/9964562.
16. Xia Chao et al., Sustainable application of sodium removal from red mud: cleaner production of silicon-potassium compound fertilizer, *Journal of Cleaner Production*, 352, 2022, 131601. https://doi.org/10.1016/j.jclepro.2022.131601.