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Process Route Design for Upgrading Zankan Lithium Ore toward Lithium-Ion Battery Production

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Abstract

Lithium is a vital industrial mineral used in ceramics, glass, batteries, and grease. Despite Nigeria's abundant lithium deposits, many remain underutilized due to limited beneficiation research targeted at lithium-ion battery production. This research involved the chemical, physical, and mineralogical characterization of the raw head sample of Zankan lithium ore. Comminution assessment was carried out to determine the liberation size and work index. Chemical analysis of the head sample was conducted using Atomic Absorption Spectrometry (AAS) and X-Ray Fluorescence (XRF), followed by X-Ray Diffraction (XRD) to establish the mineral phases present. The ore was concentrated via froth flotation using palm kernel oil as a collector, sodium silicate as a depressant, pine oil as a frother, and Na2CO3 and H2SO4 to maintain a pH of 9.5. Chemical analysis revealed that the head sample contains 2.04% Li2O. The primary lithium-bearing minerals identified were spodumene (13%), amblygonite (13%), and lepidolite (9%). The economic liberation size and Bond work index were determined to be 125 µm and 12.2 kWh/t, respectively. Flotation yielded a concentrate containing 3.36% Li2O (composed of 16% spodumene and 4% amblygonite) with a lithium recovery of 73%, a concentration ratio of 0.8, and an enrichment ratio of 1.7. The optimum flotation parameters were determined to be 125 µm particle size, 5 minutes conditioning time, and a pH of 9.5. Pre-concentration via magnetic and gravity methods prior to flotation is recommended to enhance operational efficiency.

Keywords: Comminution, Liberation Size, Concentration, Ore, Lithium, Process Route, Froth Flotation

Introduction

Concentration involves the separation of valuable minerals from gangue following comminution. Industrial-scale separation utilizes physical and physicochemical properties, including color (optical sorting), density (gravity concentration), magnetic/electrical susceptibility (magnetic/ electrostatic separation), and surface chemistry (froth flotation).

Lithium is the lightest alkali metal, with global mine production and reserves estimated at 77,000 metric tons and 17,000,000 metric tons, respectively. Due to its low standard electrode potential, lithium is a crucial component in energy storage devices, with over 65% of global production consumed by the battery industry. With the expansion of electric vehicles and portable electronics, global demand for lithium carbonate equivalent (LCE) is projected to grow significantly.

Primary lithium sources comprise continental brines (0.06%–0.15% Li) and hard-rock pegmatite deposits. The major economic pegmatitic minerals include spodumene ($LiAlSi_2O_6$, up to 8.0% Li_2O), petalite ($LiAlSi_4O_{10}$, 4.9% Li_2O), lepidolite ($K(Li,Al)_3(Si,Al)_4O_{10}(F,OH)_2$, 7.7% Li_2O), and amblygonite ($LiAlPO_4(F,OH)$). Due to overlapping physicochemical properties between lithium minerals and associated silicate gangue (e.g., quartz, feldspar, mica), effective flotation separation requires precise conditioning and reagent combination.

Problem Statement and Research Objective

Although significant pegmatite deposits exist in Nigeria, such as the deposit located at Zankan in Jema'a Local Government Area, Kaduna State (9° 37' 0" N, 8° 32' 0" E), a lack of systematic process designs for upgrading local deposits to battery-grade specifications persists. This study aims to quantify the physical, chemical, and mineralogical characteristics of Zankan lithium ore and establish an optimized process flow route for beneficiation.

Sampling and Preparation

A bulk sample of 10 kg was collected across four sampling pits at the Zankan deposit. The sample was homogenized, crushed, and ground. A 0.5 kg split was allocated for mineralogical and elemental analysis, while 3.5 kg was allocated for comminution and flotation tests.

Chemical and Mineralogical Characterization

Elemental composition was determined using X-Ray Fluorescence (XRF) and Atomic Absorption Spectrometry (AAS). Phase identification of the head sample and flotation products was performed via X-Ray Diffraction (XRD).

Comminution Studies

Liberation Size Determination: A 500 g representative sample was ground and subjected to sieve analysis using a √2 series on a Ro-Tap shaker until 100% passing was achieved. Metal deportment analysis across screen fractions was evaluated to establish the optimal liberation size.

Work Index Determination: The modified Bond Work Index method was applied using a reference sample (Itakpe Iron Ore) under identical milling conditions:

$$Wir = Wit = Wir10 * [(10 / \sqrt{Pr} - 10 / \sqrt{Fr}) / (10 / \sqrt{Pt} - 10 / \sqrt{Ft})]$$

Specific grinding energy (W) was calculated using Bond's equation:

$$W = Wit * (10 / \sqrt{Pt} - 10 / \sqrt{Ft})$$

where Fr and Ft are the 80% passing sizes of feed to ball mill for reference and test samples, Pr and Pt are the 80% passing product sizes, and Wit is the Bond Work Index (kWh/t).

Froth Flotation and Metallurgical Accounting

Direct froth flotation was performed using sodium silicate as a depressant, palm kernel oil (PKO) as a collector, and pine oil as a frother. The pH was maintained at 9.5 using Na2CO3 and H2SO4. Conditioning time was held at 5 minutes with a feed particle size of 125 µm.

Metallurgical performance was evaluated using standard expressions:

- Recovery (R) = [c * (f - t) / (f * (c - t))] * 100
- Ratio of Concentration (RC) = C / F
- Enrichment Ratio (ER) = c / f

where F and C represent feed and concentrate mass weights, and f, c, and t represent the assays (%) of feed, concentrate, and tailings, respectively.

Chemical and Mineralogical Composition

XRF and AAS analysis of the head sample established major oxide fractions and initial lithium concentration. Mineralogical phases determined via XRD are summarized in Table 1.

Parameter / Mineral	Value / Content
SiO2	75.22%
Al2O3	20.51%
K2O	1.14%
CaO	1.15%
Fe2O3	0.70%
P2O5	0.05%
Head Grade (Li2O)	2.04%
Spodumene (LiAlSi2O6)	13%
Amblygonite (LiAlPO4(F,OH))	13%
Lepidolite (K(Li,Al)3(Si,Al)4O10(F,OH)2)	9%
Gangue Minerals	Quartz, Muscovite, Chlorite, Osumilite, Illite, Garnet

Table 1: Composition and Mineralogy of Zankan Lithium Ore Head Sample

Comminution Parameters

Sieve analysis showed an economic liberation particle size at 125 µm, where 50% cumulative passing was achieved with the highest single-fraction metal deportment (0.464). The calculated Bond Work Index was 12.2 kWh/t, classifying the Zankan lithium ore as moderately hard.

Flotation and Metallurgical Balances

Following direct froth flotation, XRD analysis of the concentrate showed an increase in spodumene to 16% and amblygonite to 4%, while lepidolite was not detected in the concentrate product, indicating reagent selectivity under the controlled pH environment. Key metallurgical metrics are summarized in Table 2.

Operational Parameter	Value / Flotation Condition
Target Particle Size	125 µm
Conditioning Time	5 minutes
pH / Modifiers	9.5 (Na2CO3 / H2SO4)

Operational Parameter	Value / Flotation Condition
Collector	Palm Kernel Oil (PKO)
Depressant	Sodium Silicate
Frother	Pine Oil
Concentrate Grade (Li2O)	3.36%
Lithium Recovery (R)	73.0%
Ratio of Concentration (RC)	0.8
Enrichment Ratio (ER)	1.7

Table 2: Metallurgical Performance and Process Parameters

PROCESS FLOWSHEET ALIGNMENT

The developed process flowsheet integrates primary and secondary comminution, hydrocyclone classification to 125 µm, conditioning with Palm Kernel Oil, Sodium Silicate, and Pine Oil at pH 9.5, followed by rougher, cleaner, and scavenger flotation stages to output a high-grade Li2O concentrate.

Conclusion

- The untreated Zankan lithium ore has a head grade of 2.04% Li2O, composed of spodumene (13%), amblygonite (13%), and lepidolite (9%).
- Comminution testing established an economic liberation size of 125 µm and a Bond Work Index of 12.2 kWh/t.
- Froth flotation using Palm Kernel Oil, Sodium Silicate, and Pine Oil at pH 9.5 upgraded the ore to 3.36% Li2O with a recovery of 73%, a concentration ratio of 0.8, and an enrichment ratio of 1.7.

Recommendations

- The upgraded Zankan lithium concentrate is suitable for downstream conversion into lithium carbonate/hydroxide for lithium-ion battery manufacturing.
- Pre-concentration stages incorporating gravity and magnetic separation should be integrated prior to flotation to reject heavy iron-bearing gangue and reduce energy consumption during fine milling.

REFERENCES

Aghamirian, M. (2021). An overview of spodumene beneficiation. Proceedings of the 44th Annual Canadian Mineral Processors Conference, 141–153.

Bulatovic, S. M. (2015). Handbook of Flotation Reagents: Chemistry, Theory and Practice: Volume 3: Flotation of Industrial Minerals. Elsevier, Amsterdam, pp. 41–56.

Filippov, L. O. (2024). Beneficiation techniques for complex lithium pegmatite ores. Minerals Engineering, 180, 107–119.

Garrett, D. E. (2020). Handbook of Lithium and Natural Calcium Chloride (1st ed.). Elsevier, pp. 1–196.

Harben, P. W. (2023). Lithium minerals and compounds. In The Industrial Minerals Handbook (4th ed.). Industrial Minerals Information Ltd., UK, pp. 184–192.

Karrech, A., Azadi, M. R., & Elchalakani, M. (2020). Progress and trends in lithium extraction from hard rock ores. Minerals Engineering, 157, 106–118.

Menendez, M. (2020). Optimization of spodumene flotation. European Journal of Mineral Processing and Environmental Protection, 4, 130–135.

Shan, L., Yu, X., & Chen, Y. (2020). Flotation behavior and mechanism of lithium pegmatites. Journal of Materials Research and Technology, 9(4), 8120–8130.

Sousa, R. (2021). Flotation of lithium ores to obtain high-grade Li2O concentrates: Mineralogical limitations. International Journal of Mining, Material, and Metallurgical Engineering, 5, 12–22.

U.S. Geological Survey. (2020). Mineral Commodity Summaries 2020: Lithium. U.S. Geological Survey, Reston, VA.

Wang, X., Yu, J., & Chen, P. (2020). Surface properties and flotation separation of spodumene and associated minerals. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 592, 124–135.

Wills, B. A., & Finch, J. A. (2016). Wills' Mineral Processing Technology (8th ed.). Butterworth-Heinemann, Oxford.