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LITHIUM-ION ENRICHMENT FLOWSHEET FOR NIGERIA'S LITHIUM ORE

E.O.A. Damisa
Mining Engineering Programme, Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria, Nigeria
TETFund Centre of Excellence for Renewable Energy, Kaduna Polytechnic, Kaduna, Nigeria

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Corresponding author's details: eoadamisa@abu.edu.ng or eoadamisa@gmail.com

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ABSTRACT

The demand for lithium minerals has increased considerably in recent years due to the application of lithium compounds in renewable energy systems. Spodumene is the main lithium bearing mineral which is currently being exploited in Nigeria due to its high lithium content and the extensive occurrence of deposits across pegmatitic regions of the country. This paper focuses on the techniques used in the beneficiation of lithium minerals from hard rock pegmatite ores with special focus of flotation process and the production of lithium ion (Li^+) using the electrolytic process. Flotation technique is used as a process route for the separation of lithium minerals from the ores even though dense medium separation (DMS) offers an alternative. The close similarity in chemical and physical properties between lithium minerals and associated gangue minerals complicates the beneficiation of lithium minerals from ores. Surface chemistry of minerals, type of collector, pulp pH, chemical pre-treatment methods and the presence of slimes play key roles, hence the choice of flotation technique. For the secondary processing, electrolytic process is discussed to produce any of lithium compounds including lithium carbonate ($L_{i2}CO_3$), lithium oxide (Li_2O), and lithium hydroxide (LiOH). Conventional and common lithium metal extraction has typically involved acid or alkaline leaching of lithium-containing ores (spodumene) is used to dissolve the lithium from the spodumene concentrate, followed by extraction of the metal, concentration of the lithium solution and then conversion to lithium ion in the form of lithium carbonate, lithium oxide or lithium hydroxide using the electrolytic process.

1. INTRODUCTION

Energy is a big deal and the world is witnessing a rapid shift towards a cleaner and more sustainable energy future. Governments, corporations and individuals have recognized the urgent need to address the impacts of climate change and therefore, there is a growing demand for energy sources that are less carbon-intensive. The current energy transition therefore is the shift from hydrocarbon sources (including oil, natural gas and coal) to renewable and cleaner energy sources in order to reduce greenhouse gas (carbon dioxide, methane etc.) emissions and combat climate change.

1.1 Link between energy transition and critical mineral resources.

The energy transition is intricately linked with critical mineral resources or elements, which are essential for powering clean energy technologies like solar panels, wind turbines and electric vehicle batteries. Critical minerals are minerals that are essential to the economy and national security of a country, but whose supply chain is vulnerable to disruption (IEA, 2022). An energy system powered by clean energy technologies differs profoundly from one fuelled by traditional hydrocarbon resources. Building solar photovoltaic (PV) plants, wind farms and electric vehicles (EVs) generally requires more minerals than their fossil fuel-based counterparts. A typical electric car requires six times the mineral inputs of a conventional car and an onshore wind plant require nine times more mineral resources than a gas-fired power plant. Since 2010, the average amount of minerals needed for a new unit of power generation capacity has increased by 50% as the share of renewables has risen. The types of mineral resources used vary by technology. Lithium, nickel, cobalt, manganese and graphite are crucial to battery performance, longevity and energy density. Rare earth elements are essential for permanent magnets that are vital for wind turbines and EV motors. Electricity networks need a huge amount of copper and aluminium, with copper being a cornerstone for all electricity-related technologies (IEA,2022). One of the most important minerals/elements is lithium, which is crucial for battery storage, with demand expected to increase by 488% to meet future needs (The IEA, 2020). It is a surprise that the world's demand for lithium exploitation is growing every day and is especially driven by an increased lithium use in new consumer electronic battery technologies and electric cars (Clarke, 2013).

1.2 Enrichment flowsheet for Lithium ion

By developing an enrichment flowsheet, mining investors in the Nigerian mining industry can optimise their lithium mineral processing and lithium metal extraction operations, leading to improved efficiency, reduced costs and increased profitability. In addition, efficient and sustainable practices in the mining industry are a boost to Nigeria's Energy Transition Plan (ETP) which was created in 2021 with COP26 support, prompting Nigeria's net-zero commitment by 2060. The plan has government approval and presents a $23 billion opportunity for supporting financiers and partners (Damisa, 2024).

Lithium is a chemical element with the symbol Li and atomic number 3. It is a soft, silverywhite alkali metal. Under standard conditions, it is the least dense metal. It is an alkali metal and like all alkali metals, lithium is highly reactive and flammable (Garrett, 2004) Therefore, it must be stored in vacuum, inert atmosphere, or inert liquid such as purified kerosene or mineral oil. It is widely employed in various important applications such as lithium-ion batteries, glass, ceramic, metallurgy, lubricant, nuclear energy, and organic chemistry due to its high electrochemical activity, specific heat capacity, redox potential and other excellent properties. When cut, it exhibits a metallic lustre, but moist air corrodes it quickly to a dull silvery gray, then black tarnish. It never occurs freely in nature, but only in (usually ionic) compounds, such as pegmatitic minerals. Due to its solubility as an ion, it is present in ocean water and is commonly obtained from brines. Lithium metal is isolated electrolytically from a mixture of lithium chloride and potassium chloride (Haynes, 2014).

The alkali metals are also called the lithium family, after its leading element. Like the other alkali metals (which are sodium (Na), potassium (K), rubidium (Rb), caesium (Cs), and francium (Fr)), lithium has a single valence electron that is easily given up to form a cation (Krebs, 2006). Because of this, lithium is a good conductor of heat and electricity as well as a highly reactive element, though it is the least reactive of the alkali metals. (Lithium, Britannica encyclopedia, 2020). Lithium's low reactivity is due to the proximity of its valence electron to its nucleus (the remaining two electrons are in the 1s orbital, much lower in energy, and do not participate in chemical bonds)(Krebs,). Molten lithium is significantly more reactive than its solid form (Handbook of Chemistry & Physics *,2017).*

1.3 Lithium and its compounds

Lithium and its compounds have several industrial applications, including heat-resistant glass and ceramics, lithium grease lubricants, flux additives for iron, steel and aluminium production, lithium batteries, and lithium-ion batteries. These uses consume more than threequarters of lithium production. (Emsley, 2011) and (Jefferson, 2014)

Although lithium is widely distributed on Earth, it does not naturally occur in elemental form due to its high reactivity. (Krebs, 2006). The total lithium content of seawater is very large and is estimated as 230 billion tonnes, where the element exists at a relatively constant concentration of 0.14 to 0.25 parts per million (ppm), or 25 micromolar; higher concentrations approaching 7 ppm are found near hydrothermal vents.(Lithium Occurrence, 2009.*).* Estimates for the Earth's crustal content range from 20 to 70 ppm by weight. Lithium constitutes about 0.002 percent of Earth's crust (lithium: Britannica encyclopedia, 2020).

In keeping with its name, lithium forms a minor part of igneous rocks, with the largest concentrations in granites. Granitic pegmatites also provide the greatest abundance of lithiumcontaining minerals, with spodumene and petalite being the most commercially viable sources, (Garrett, 2004) Pegmatites are intruding rock units which form when mineral-rich magma intrudes from magma chambers into the crust. Pegmatites are commonly zoned, coarse-grained intrusive igneous rocks that form in the late stages of magma crystallisation and mostly have an overall granitic composition. Pegmatite is an exceptionally coarse-grained plutonic igneous rock. Most pegmatites have a mineralogical composition of granite but composition has no defining importance here. Pegmatites may have any imaginative magmatic composition and they are actually known to contain a large number of unusual minerals. Pegmatite is a very coarse-grained igneous rock. Simple pegmatites are composed of large crystals of ordinary minerals. (Jahns, 2007).

Chile is estimated to have the largest reserves by far (9.2 million tonnes), (U.S. Geological Survey, 2018). In Cornwall, England, the presence of brine rich in lithium was well known due to the region's historic mining industry, and private investors have conducted tests to investigate potential lithium extraction in this area (Bliss, 2021*).* The development of lithium ion batteries increased the demand for lithium and became the dominant use in 2007 (*"Minerals Yearbook*, *2007).* With the surge of lithium demand in batteries in the 2000s, new companies have expanded brine isolation efforts to meet the rising demand (Kogel, 2006*).* It has been argued that lithium will be one of the main objects of geopolitical competition in a world running on renewable energy and dependent on batteries, but this perspective has also been criticised for underestimating the power of economic incentives for expanded production (Overland, 2019). However, the transition to clean energy is not as simple as replacing fossil fuels with renewable sources such as wind, solar and hydro. In order to power the clean energy revolution, we need a range of critical minerals that are essential for the generation, transmission and storage of energy. Critical minerals/elements are a big deal in this scenario and lithium commands a preeminent position, particularly due to its role in powering electric vehicles (EVs) and storing intermittent energy generated by renewable sources.

2. LITERATURE REVIEW ON LITHIUM-ION ENRICHMENT

Lithium-ion enrichment covers both the geological processes that create natural lithium deposits and the technological methods for extracting and concentrating lithium-ions for use in batteries and potential nuclear applications. The focus of this paper is on technological methods for extracting and concentrating lithium-ions with particular attention to ores.

2.1. Geological Processes and Natural Enrichment

Lithium is a highly incompatible element, meaning it does not fit easily into the crystal structures of common rock-forming minerals. This results in its concentration in the residual fluids during geological processes **(**Bowell, et al, 2020)

- Magmatic Processes: Lithium concentrations increase systematically in newly formed partial melts, ultimately leading to high concentrations in pegmatites and greisens (types of igneous rocks).
- Brine and Geothermal Waters: Weathering and other processes can leach lithium from rocks into aqueous solutions. Over time, in closed-basin salars (salt flats) and geothermal systems, natural evaporation processes lead to significant enrichment of Li^+ ions to economically recoverable concentrations.

2.2. Extraction and Enrichment Technologies

To meet the increasing demand for lithium, especially for lithium-ion batteries, various extraction and enrichment technologies have been developed from both primary (natural) and secondary (recycled) sources **(**Halkes et al**.,**2024)**.**

- Direct Lithium Extraction (DLE): This is a key focus in recent literature for extracting lithium from low-concentration aqueous solutions like brines and seawater. Technologies reviewed include: ○ Adsorption: Using selective adsorbents to capture lithium ions.
  - Membrane Separation: Processes like forward osmosis and electrolysis using nanoporous membranes to separate and concentrate Li^+ ions from other ions (e.g., Mg^{2+}, Na^+).
  - Electrochemical Methods: Utilizing redox reactions or electrochemical pumping with solid electrolytes to recover and enrich lithium with high selectivity and potential energy output.

Recycling from Spent Batteries: A significant body of literature addresses the recovery of lithium from used lithium-ion batteries to foster a circular economy **(**Lv et al, 2014):

- Methods typically involve:

- Pretreatment: Processes like crushing and thermal treatment to liberate components.
- Leaching: Using inorganic or organic acids to dissolve the cathode materials.
- Separation and Enrichment: Techniques like solvent extraction, precipitation, and electrolysis to isolate and enrich lithium from the resulting leach liquors.

2.3. Lithium Isotope Enrichment

A separate but related topic in the literature is the enrichment of specific lithium isotopes, particularly ^{6}Li, for applications in nuclear fusion reactors. This involves highly specialized chemical exchange or electrochemical processes with high separation factors.

3. SOURCES OF LITHIUM MINERALS IN NIGERIA

Lithium deposits in Nigeria have been part of the land for millions of years, locked in pegmatites that formed during the Pan African geological shake up around 600 million years ago (Hassan, 2014). The Nigerian Geological Survey Agency has been mapping out high-grade lithium deposits across the country since 2018, identifying areas like Nasarawa's Keffi district and Kwara's southwest as rich in lithium. These areas contain pegmatite rocks initially thought to be limited to a pegmatite belt containing hundreds of pegmatite dykes and veins intruding basement complex rocks comprising quartz, mica, schist and granite gneisses. They are reported to be associated with tin and columbitetantalite mineralization (Garba 2003; Okunlola 2005; Okunlola & Ocan, 2009) in (Umar, 2024). Okunlola (2005) in (Hassan, 2024) classified Nigeria's pegmatite belt into seven (7) broad fields namely: Nasarawa-Keffi, Ijero-Aramoko, Ibadan–Osogbo, Lema-Share, OkeOgun, Kabba-Isanlu and Kushaka-Birnin Gwari. Nigeria is rich in lithium deposits, with significant reserves found in several states, including Nasarawa, Kogi, Kwara, Ekiti, Oyo, Kaduna, Cross River, Bauchi, Niger, and the Federal Capital Territory. These deposits are scattered across a 450-mile belt, known as the "Lithium Belt," which stretches from the southwest corner of Nigeria to Kano in the north. Recent lithium ore exploitation across the country has widened the pegmatite belt to cover almost the entire Nigerian landmass underlain by basement complex (Figure 1). Lithium bearing pegmatites have been established to occur in many states including Nasarawa, Oyo, Osun, Ogun, Ekiti, Kogi, Kwara, Kebbi, FCT, Adamawa, Taraba, Cross River, Niger and Kaduna States (Hassan, 2024). The potential of Nigeria's lithium reserves is significant, with some pegmatites hitting grades as high as 13% lithium oxide, far above the global mining cut-off. This could position Nigeria as a key player in the global lithium supply chain, particularly as demand for the metal grows due to its use in electric vehicle batteries and other renewable energy technologies (Hassan, 2024).

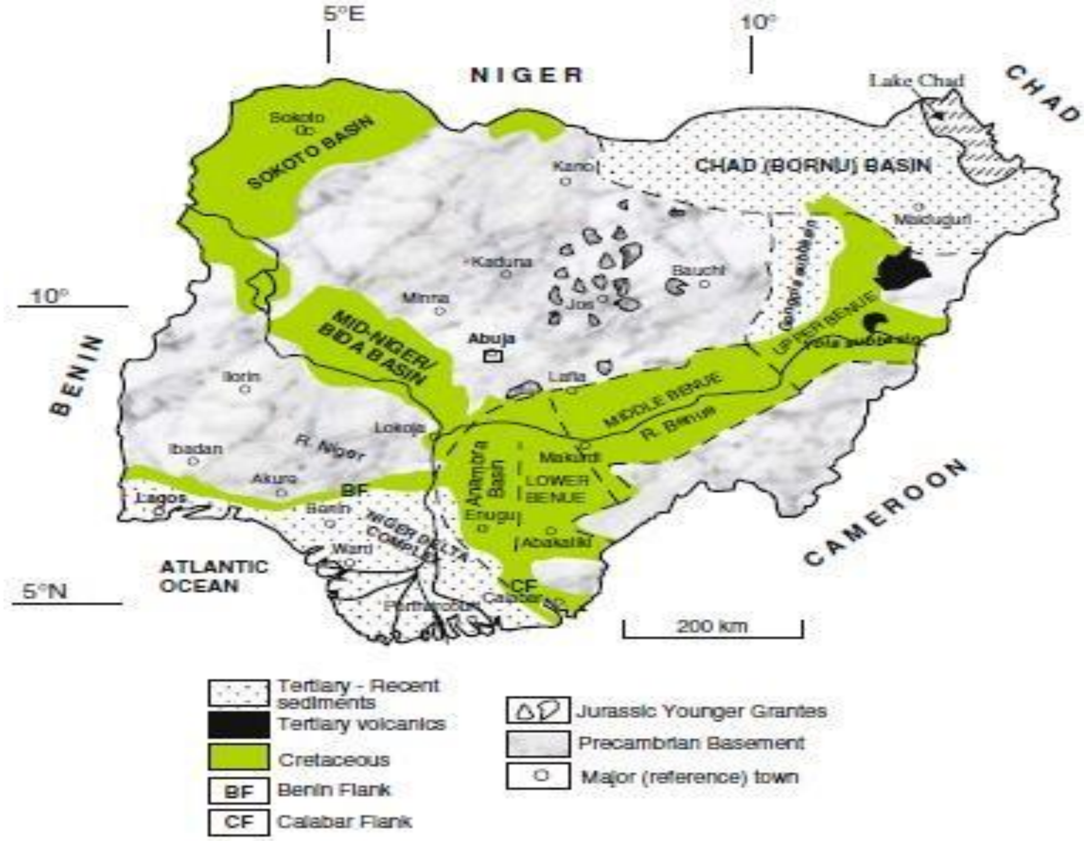


Figure 1**:** "Lithium Belt" Nigerian landmass underlain by basement complex

4. METHODS OF LITHIUM EXTRACTION

Historically, two primary methods have dominated lithium extraction:

*Solar Evaporation from Brine****:*** Lithium-rich brine is pumped into vast evaporation ponds, where the sun concentrates lithium over 12–24 months and hard rock mining (An, 2012).

Lithium Hard Rock Ores: Lithium-bearing minerals like spodumene are extracted, crushed and chemically processed.

The main source of lithium at present in Nigeria is the hard rock ore of the metal. There are good number of minerals containing lithium, however, only four are actively mined for lithium production. These include: Spodumene, which is the most common by far. Therefore, this paper focuses primarily on spodumene, which is the major lithium mineral and commonly sold as-mined or processed.

5. DEVELOPING LITHIUM ENRICHMENT FLOWSHEET

In order to develop a process flowsheet for Nigeria’s lithium deposit to produce lithium ion, certain steps must be carried out: Selection of representative samples for testing and sample preparation; analysis of the ore to determine its mineralogy, texture and chemical composition; laboratory testing to determine the lithium ore's response to various processing conditions; and finally the flowsheet design. Additionally, iterative process (starting from conceptual flowsheet) should be carried out to refine the flowsheet as needed. It is also necessary to use industry standards and best practices to ensure the flowsheet meets industry standards and incorporate such best practices in the flowsheet.

5.1 Steps to developing Nigerian Lithium Ore Enrichment Flowsheet

Developing a flowsheet for mineral processing and metal extraction involves several steps:

- Selection of representative samples for testing and sample preparation;
- *Ore characterization:* Understanding the mineralogical and chemical composition of the ore. Analysis of the ore to determine its mineralogy, texture and chemical composition;
- *Process selection*: Selecting the most suitable processes for mineral processing and metal extraction based on the ore characteristics. This means laboratory testing to determine the lithium ore's response to various processing conditions especially with regard to flotation process;
- *Flowsheet design*: Designing the flowsheet, including the sequence of unit operations and the connections between them. Additionally, iterative process (starting from conceptual flowsheet) should be carried out to refine the flowsheet as needed.
- Mass balance: Calculating the mass balance of the flowsheet to ensure that the inputs and outputs are balanced.
- *Economic evaluation*: Evaluating the economic viability of the flowsheet.
- *Laboratory and pilot-scale testing*: Laboratory and pilot-scale testing are essential for validating the flowsheet and optimizing process conditions.
- *Flowsheet optimization*: Flowsheet optimization involves identifying opportunities to improve metal recovery, reduce costs, and minimize environmental impacts.
- It is also necessary to use industry standards and best practices to ensure the flowsheet meets industry standards and incorporate such best practices in the flowsheet.

5.2 Key Considerations

Nigerian lithium ores are often associated with several minerals and elements, including: - Tantalum (Ta) and Niobium (Nb): These minerals are commonly found alongside lithium in pegmatite deposits, particularly in states like Kogi, Nasarawa and Kwara.

- Tin (Sn): Tin is another mineral often associated with lithium in Nigerian pegmatites, particularly in the Jos Plateau region.
- Beryllium (Be): Beryllium is a rare mineral found in some Nigerian lithium deposits, particularly in the Nasarawa and Kogi states.
- Cesium (Cs): Cesium is a rare alkali metal often associated with lithium in Nigerian pegmatites. - Silica (SiO_2) and Alumina (Al_2O_3): These minerals are common gangue minerals found in Nigerian lithium ores.
- Rare Earth Elements (REEs): Some Nigerian lithium deposits, particularly in the Sokoto Sedimentary Basin, contain REEs like neodymium (Nd) and dysprosium (Dy).

These associated minerals can impact the processing and extraction of lithium, and their presence may require specialized processing techniques.

5.2.1 These are very important in the development of the flowsheet. Ore type and mineralogy. Understanding the associated elements present in lithium ores is crucial for optimizing processing conditions and achieving economic extraction. In terms of the elements often associated with lithium minerals, the following are very important in the development of the flowsheet and overall processing of lithium ores: Aluminium (Al), Silicon (Si), Iron (Fe), Manganese (Mn), Magnesium (Mg), Calcium (Ca), Sodium (Na), Potassium (K), Rubidium (Rb), Cesium (Cs), Tantalum (Ta), Niobium (Nb), Tin (Sn), Tungsten (W) and Molybdenum (Mo). The type of ore and its mineralogy play a crucial role in determining the flowsheet, see Table 1. These elements may be present in varying amounts and can impact the processing and extraction of lithium. Some associated elements, like tantalum and niobium, can be valuable by-products, while others, like iron and silicon, may need to be removed to produce high-purity lithium. The associated minerals/elements can also affect the mineralogy and chemistry of the ore, influencing the choice of processing methods and the efficiency of lithium extraction.

5.2.2 *Metal recovery*: The flowsheet should be designed to maximize metal recovery while minimizing costs.

5.2.3 *Environmental considerations*: The flowsheet should be designed to minimize environmental impacts.

5.2.4 *Scalability*: The flowsheet should be scalable to accommodate changes in ore throughput or grade.

Table 1. Possible associated minerals with Nigerian lithium ores

Mineral	Formula
Coltan (Columbite-Tantalite)	$(Mn,Fe)(Ta,Nb)_2O_6$
Columbite	$(Mn,Fe)Ta_2O_6$
Tantalite	$(Fe,Mn)Ta_2O_6$
Quartz	(SiO_2)
Feldspar	$(KAlSi_3O_8– NaAlSi_3O_8 – CaAlSi_3O_8)$
Mica	$(K_2Al_4(Al_2Si_6O_{20}(OH)_4)$
Amphibole (Hornblende)	$Ca2(Mg,Fe,Al)5Si6Al_2O_{22}(OH)_2$
Pyroxene (Diopside)	$(MgCaSi_2O_6)$
Apatite	$(Ca_5(PO_4)_3(F,Cl,OH)$
Zircon	$(ZrSiO_4)$
Cassiterite	(SnO_2)
Wolframite	$((Fe,Mn)WO_4)$
Bismuthinite	(Bi_2S_3)
Pyrite	(FeS_2)
Galena	(PbS)
Olivine	$(Mg,Fe)_2SiO_4$
Garnet (Almandine)	$(Fe_3Al_2(SiO_4)_3)$
Tourmaline	$(Na,Mg,Al,Li,B)_3Al_6(BO_3)3Si_6O_{18}(OH)_4$

6. PRIMARY PROCESSING: LITHIUM ORE TO LITHIUM CONCENTRATE

Mineral processing is necessary to make raw ores profitable and technologically feasible by separating valuable minerals from waste rock (gangue). In this case, this concentration process is crucial because lithium ores contain only a low percentage of the lithium element and is uneconomical to refine directly. Mineral processing of the lithium ore creates a more concentrated material for further refining, which reduces transportation costs and improves the efficiency of downstream processes.

- Primary processing consists mainly comminution and concentration of the run-of-mine ore.
- Comminution is the *liberation* of the valuable mineral by breaking the lithium ore so that the individual mineral components of the ore become independent of each other.

- Concentration process usually adopted in lithium beneficiation is flotation technique to separate the lithium mineral from the gangue to produce an enriched portion of the lithium mineral in relation to the feed.

6.1 Flotation Technique

Flotation is a mineral processing technique used to separate valuable minerals from waste rock by altering the surface properties of the minerals and it is one of the most important techniques used in the concentration of lithium ion.

- Flotation technique involves creating a pulp of the comminuted ore and water, and then adding surfactants (collectors) that bind to the lithium minerals, making them hydrophobic (waterrepelling).
- The mixture is then agitated and air is introduced, creating bubbles to which the lithium mineral particles are attached, causing them to float to the surface, where they are skimmed off as lithium mineral concentrate.
- Flotation is a complex process and optimizing the various factors can be challenging. However, it remains the most widely used and effective technique in the processing of lithium ore containing spodumene.

The factors which may affect the lithium mineral flotation include:

Grind size: Very fine particle sizes can facilitate the liberation and separation of the lithium mineral, spodumene from its associated gangue minerals;

pH: Affects the activity of collectors and the flotation process as a system;

Collector type: Different collectors are used for different minerals, oleic acid for oxides for example;

Frother type: Affects the froth stability and mineral carrying capacity;

Temperature: Affects the flotation kinetics and mineral behaviour; *Reagent dosage*: Affects the flotation performance and cost.

Table 2. Reagents for Lithium mineral Flotation

Class of reagents	Examples of reagents
Collectors	Oleic acid, Sodium oleate, Sodium lauryl sulphate, Fatty acids (e.g., stearic acid, palmitic acid)
Frothers	Methyl isobutyl carbinol (MIBC), Ethanol, Glycols (e.g., ethylene glycol, propylene glycol)
pH modifiers	Sodium hydroxide (NaOH), Hydrochloric acid (HCl), Sodium carbonate (Na_2CO_3)
Activators	Sodium sulphide (Na_2S), Sodium metabisulphite ($Na_2S_2O_5$)
Depressants	Sodium cyanide (NaCN), Sodium silicate (Na_2SiO_3)
Flocculants	Polyacrylamide, Polyethylene oxide
Surfactants	(e.g., alkyl sulphonates, alkyl ethoxysulphates)
Polymers	(e.g., polyacrylic acid, polymethacrylic acid)
Inorganic salts	(e.g., sodium chloride, calcium chloride)

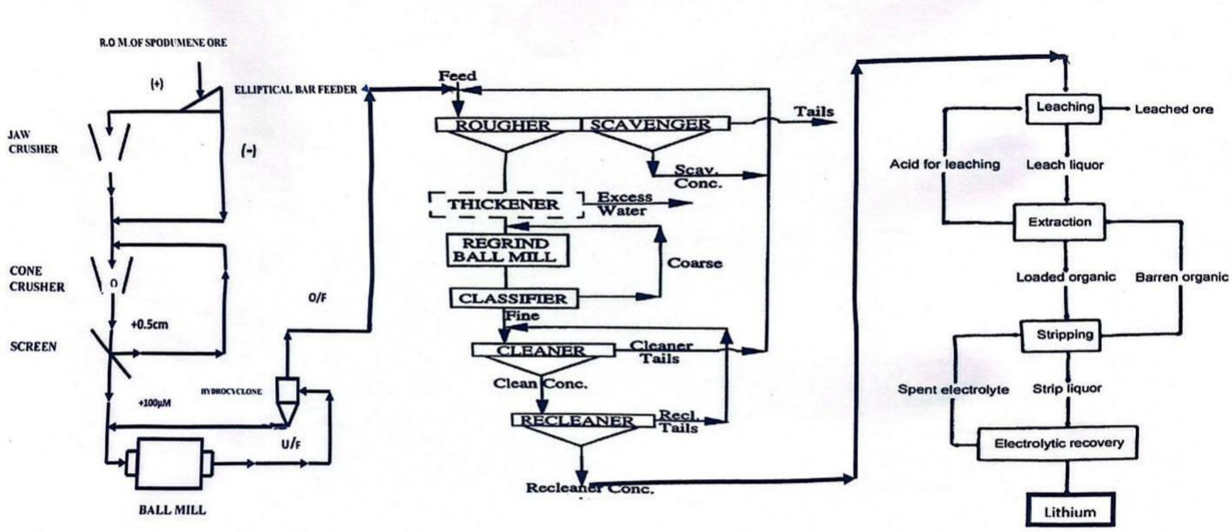
It is important to note that the type and dosage of reagents used in the Nigerian lithium mineral flotation may vary depending on the specific requirements of the operation and the characteristics of the lithium ore being processed.

6.2 Secondary processing: Conversion or extraction of the metal Li^+ from the lithium concentrate

Lithium compounds are produced in a variety of forms including lithium carbonate ($L_{i2}CO_3$), lithium oxide (Li_2O), and lithium hydroxide (LiOH). Conventional and common lithium metal extraction has typically involved acid or alkaline leaching of lithium-containing ores (spodumene) is used to dissolve the lithium from the spodumene concentrate, followed by extraction of the metal, concentration of the lithium solution and then conversion to lithium carbonate or lithium hydroxide using electrolytic process.

- The extraction process typically involves the following steps, the first two being subsidiary steps that lead to leaching process
- *Calcination*: The spodumene concentrate from primary processing is calcined to high temperatures (around 1100°C) to convert the spodumene into a more reactive form (alpha form to beta form)
- *Acid roasting*: The calcined ore is mixed with acid (usually sulphuric acid) and roasted at high temperatures (around 250°C) to break down the spodumene and release lithium.
- *Leaching*: The resulting material is mixed with water to form slurry and subjected to leaching, which allows the lithium to dissolve into the solution.
- *Precipitation*: The lithium-rich solution is then treated with a precipitating agent (such as sodium carbonate) to precipitate or strip out the lithium as lithium carbonate (Li_2CO_3) or in some cases lithium hydroxide (LiOH), depending on the precipitating agent used.
- *Electrolysis*: The concentrated solution is then subjected to electrolysis, where electric current is passed through the solution, causing the lithium ions to be reduced to lithium metal.
- *Refining*: The resulting lithium metal is then refined and purified through various processes, such as distillation or zone refining.
- All the above processes are summarized in the flowsheet. As explained above, the flowsheet is just a graphical representation of the major stages in the conversion of the ore to the metal. Some details cannot be included because of space but further details can be obtained from the author or other professionals.

FLOWSHEET FOR THE ENRICHMENT OF LITHIUM ION FROM NIGERIAN LITHIUM ORES



7. CONCLUSION

The enrichment or extraction of lithium ion from run-of-mine ore can be described as of two major stages viz. primary processing and secondary processing. The processes require careful control of conditions to achieve high recovery of the lithium mineral in the concentrate and meticulous control of the conditions to produce high purity of the lithium ion or metal. The other major technique used in the beneficiation of lithium minerals is dense medium separation (DMS). Dense media separation is usually employed for coarse gangue rejection, but can also be used to produce lithium concentrates from high grade ores. Magnetic separation technique can also be employed to separate magnetite or other forms of the mineral after roasting the concentrate. Still, froth flotation is the most popular technique because of the fine particle size feed and high recovery it offers. Spodumene from pegmatite deposits is expected to be the main source of lithium from ores in Nigeria at present although future sources would most probably include other minerals such as lepidolite, petalite, zinnwaldite, jadarite and hectorite. By developing the flowsheet, there are both technical and economic benefits that accrue to any investor in the exploitation of lithium in Nigeria. These include improved process control which can help to identify key variables and optimizing process conditions. The flowsheet would no doubt help reduce downtime, if it is well-designed, by identifying potential issues and optimizing maintenance schedules, identify potential safety hazards and optimize process conditions to minimize risks. Succinctly, by developing a flowsheet for the lithium ion (Li^+) from Nigerian ores, mining investors will optimize their lithium ore processing and lithium ion (Li^+) extraction operations, leading to improved efficiency, reduced costs and increased profitability.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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