LIFE CYCLE INVENTORIES DEVELOPMENT USING PROCESS SIMULATION FOR NICKEL SUPPLY FOR BATTERIES

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Context

Lithium-ion Batteries (LIBs)

LIBs for a fast energy transition → Electric vehicles (EVs)

Lithium-ion cell

Cathode

Separator

Electrolyte

Anode

Graphite (≈20%)

14% Ni content in a LIB
**Context**

**Nickel**

**Main resources**
- Sulfate ores
- Laterite ores

**Reserves**
- World total \(^1\) (rounded) | 130,000,000 Mt
- Top production and reserves | Indonesia

**For LIBs**
- High purity nickel sulfate | NiSO\(_4\)

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**Market demand share, by first-use sector\(^2\)**

- 2020: Stainless, primary - 36%, Batteries, primary - 6%
- 2030: Stainless, primary - 36%, Batteries, primary - 26%
- 2040: Stainless, primary - 36%, Batteries, primary - 36%

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\(^1\)USGS
\(^2\)Roskill, 2020
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Objective

Integrate process modelling and LCA to assess the environmental impact of producing battery-grade nickel sulfate through two distinct routes at varying TRL.
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**Ni extraction from laterites**

I . Mining an mineral preparation

- Indonesia
  - Laterite ores
    - Limonite
    - Saprolite

II . Production of MHP cake

- Indonesia
  - Through HPAL (TRL 8-9)
  - Through bioleaching (TRL 3-4)

III . Production of NiSO₄

- China OR Europe
  - Selective acid leaching

**Limonite ore composition**

<table>
<thead>
<tr>
<th></th>
<th>wt.%</th>
<th>wt.%</th>
<th>wt.%</th>
<th>wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goethite*</td>
<td>72.2</td>
<td>1.4</td>
<td>5.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Magnetite</td>
<td>5.6</td>
<td>1.4</td>
<td>4.1</td>
<td>0.02</td>
</tr>
<tr>
<td>Hematite*</td>
<td>0.8</td>
<td>0.9</td>
<td>7.5</td>
<td>0.1</td>
</tr>
</tbody>
</table>

*Ni containing mineral (Total NiO ~2.7%)*
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Ni extraction from laterites - Flowsheet

1. Mineral feed → Mineral preparation
2. Mineral preparation → Thickener
3. Thickener → HPAL/Bio-leach
4. HPAL/Bio-leach → Counter current decantation
5. Counter current decantation → Partial neutralization
6. Partial neutralization → Copper removal
7. Copper removal → Zinc removal
8. Zinc removal → Primary SX
9. Primary SX → MHP precipitation
10. MHP precipitation → Atmospheric leaching
11. Atmospheric leaching → Selective precipitation
12. Selective precipitation → SX
13. SX → Effluent evaporation
14. Effluent evaporation → MHP cake
15. MHP cake → Crystallization
16. Crystallization → NiSO₄
17. Crystallization → CoSO₄
18. Crystallization → Na₂SO₄
Nickel extraction from laterites

High pressure acid leaching (HPAL)

Main characteristics

Main hydrometallurgical way for high-grade ores

- Based on acid dissolution of Fe oxides (mainly Goethite),
- Requires sulfuric acid to dissolve iron oxides and other minerals
- High pressure achieved by injecting pressurized air and steam in the autoclave
- High energy consumption (to keep high pressure and temperature)
Nickel extraction from laterites

Reductive bioleaching

New biological pathway to extract Ni and Co

- Based on the use of acidophilic bacteria to reduce iron and manganese oxides

- Three main steps:
  - Microbial growth in aerobic conditions (air injection) supported by the oxidation of sulfur
  - Fe bio-reduction by the same bacteria but in anaerobic conditions
  - Reductive leaching of manganese oxides and increase of the goethite acid leaching

\[ S^0 + O_2 + H_2O \rightarrow H_2SO_4 \]  
\[ 6Fe^{3+} + S^0 + 4H_2O \rightarrow 6Fe^{2+} + SO_4^{2-} + 8H^+ \]  
\[ FeOOH + 3H^+ \rightarrow Fe^{3+} + 2H_2O \]  
\[ MnO_2 + 2Fe^{2+} + 4H^+ \rightarrow Mn^{2+} + 2Fe^{3+} + 2H_2O \]
Coupling process simulation and LCA

Methodology

Chemical analysis + estimated mineralogy → Modelled Mineralogy, considering main Ni and Co carries and distribution

For HPAL (TRL 8-9)
- Building of the HPAL model using primary data
- Selection of main fluxes for LCI
- Life cycle impact assessment and scenario comparison

For Bioleaching (TRL 3-4)
- Combination of experimental data and literature

Three scenarios in terms of Ni dissolution yield:
- Maximum (80%)
- Average (54%)
- Minimum (9%)
Preliminary results

Bioleaching scenarios

ReCiPe 2016 Midpoint (H)

Functional unit | Production of 1kg NiSO₄

Min  Average  Max
Preliminary results

Bioleaching vs HPAL

Functional unit | Production of 1kg NiSO₄₄
At equivalent Ni production 25 – 30 t/h

ReCiPe 2016 Midpoint (H)
Preliminary conclusions

Environmental impact “hotspots”

- In general, HPAL has greater environmental impacts, particularly regarding global warming, terrestrial acidification and ecotoxicity, land use and resource scarcity. The main reason for this is the high energy consumption of the process and the important amount of acid per ore mass.

- Reductive bioleaching impacts are higher for impact categories related to water acidification and ecotoxicity. This is related to:
  - The use and disposal of nutrients necessary for bacteria (mainly $\text{NH}_4^+$ and $\text{PO}_4^{3-}$),
  - The use of calcite for pH control, which increases the presence of $\text{SO}_4^{2-}$ in solid residues.

- Therefore, a reduction of nutrient consumption, their recycling in the process and/or their valorization will decrease these impacts.

- These results serve to identify the environmental impact hotspots and the parameters to optimize for enhancing the environmental performance of bioleaching compared to HPAL.

Process simulation may help to fill the lack of data for low TRL technologies and, in turn, LCA may facilitate the eco-conception of processes at low TRL.
Thank you for your attention!

Q&A

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