Status and Prospect of Polymetallic Nodules Process Development in Korea.

2018. 9.

Korea Institute of Geoscience and Mineral Resources

KIGAM
Research System for developing Ocean Minerals in Korea

Korea Government
(Ministry of Maritime Affairs and Fisheries)

- Exploration
  - KIOST

- Mining
  - KRISO

- Process
  - KIGAM
    - DB Metal
    - LS Likko Copper
    - SNNC
    - SungEel HiTech

- KIOST : Korea Institute of Ocean Science and Technology
- KIGAM : Korea Institute of Geoscience and Mineral Resources
- KRISO : Korea Research Institute of Ships & Ocean Engineering
  An affiliate of KIOST
Costs for Nodules Development

Source: KIOST report (2017)
## Road Map for Process Development in Korea

<table>
<thead>
<tr>
<th>process</th>
<th>period</th>
<th>contents</th>
</tr>
</thead>
</table>
| Basic study                                  | 1994 ~ 2002 | - Basic research on processing methods  
                                             |          | - Selection of favorite process (smelting-wet method)                  |
| Development of unit operations (Lab scale)   | 2003 ~ 2006 | - Process development of unit operations (Reduction, Smelting, Leaching, Separation, Recovery)  
                                             |          | - Si-Mn product                                                         |
| Technology improvement (scale up tests)      | 2007 ~ 2011 | - Technological improvement of unit operations  
                                             |          | - Integrated process system  
                                             |          | - Scale up tests (50kg)                                                  |
| Applied technology for commercialization (Pilot tests) | 2012 ~ 2015 | - Pilot tests (2ton/day-pyro, 200kg/day-hydro)  
                                             |          | - Recovery of rare earth metals  
                                             |          | - Conceptual design for commercial plant                                 |
Methods of Nodules Processing

Smelting — Leaching

Roasting — Leaching

Leaching

Matte — Leaching

Alloy — Leaching

Reduction. R — Ammonical L.

Sulphating R. — Water Leaching

Chloridizing R. — Water Leaching

HCl Leaching

H\textsubscript{2}SO\textsubscript{4} Leaching

High pressure Leaching

Selective

Non-selective

Ammonical Leaching
Smelting-Leaching Process

- Technical side (best known)
- Smaller environmental impact
- Easy to prepare Mn alloy
- Great flexibility for raw materials (metal wastes, scraps, manganese crust)
- Low burden for hydrometallurgical process (1/10)
- High energy required
Smelting-Leaching Process

- **Pre-Reduction**
  - Nodules
  - Crushing, Drying
  - Alloy

- **Reduction-Smelting**
  - Slag

- **Sulfiding, Oxidation**
  - Si-Mn

- **Leaching**
  - Matte

- **Solvent Extraction Electrowinning**
  - Solution
  - Cu Metal
  - Cu, Ni, Co, Fe
  - Mn, Si, Al

- **Electrowinning**
  - Co, Co salt
  - Ni, Ni salt

- **Recovered Metals**
  - Fe₂O₃
Rotary Kiln for Reduction Roasting
Reduction Smelting (Alloy preparation)

DC Arc Furnace (Batch type, 50kg/Ch.)

<table>
<thead>
<tr>
<th>element</th>
<th>Ni</th>
<th>Co</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content (%)</td>
<td>16.94</td>
<td>2.45</td>
<td>13.20</td>
<td>67.02</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Alloy weight: 10-15% of nodules
Reduction Smelting (Continuous type)

- Joint research with Dongbu Metal

DC Arc Furnace (Continuous type)
Preparation of Si-Mn from Slag

- Joint research with Dongbu Metal

Slag from Smelting process

Si-Mn
Preparation of Matte

- Matte: easy to crush and to leach

- Add sulfur source to alloy

- Sulfur source:
  - elemental sulfur,
  - pyrite,
  - waste gypsum
Leaching of Matte

Leaching Solution

Residue($\text{Fe}_2\text{O}_3$)

Batch type autoclave (15 Liter)
Autoclave for leaching matte (Continuous)

- Joint research with LS-Nikko Copper Inc.

Continuous type autoclave (40 Liter)
Separation of Cu, Ni and Co from Leach liquor

Leaching Solution (Cu, Ni, Co, Fe)

- Cu SX
- Ni, Co SX
- Ni, Co EW
- Co EW
- Ni EW

Cu Cathode

Co Cathode

Ni Cathode

Residue (Fe)

Before SX | After SX | Stripping
Mixer-settler for solvent Extraction

mixer-settler

View of mixer-settler
Electro-winning to produce metals

View of electro-winning system
Cu, Co and Ni product

Cu >99.9%

Co >99.9%

Ni >99.9%
Control Panel for Pilot Plant of SX-EW system
Data Analysis of SX-EW system
Treatment of Wastes with Mn nodules

Spent battery, catalyst, metal scrap, plating sludge, etc.

Nodules → Crush & Drying → Reduction, Smelting → Alloy Phase (Recovery)

Roasted spent CMB (Cobalt manganese Bromide) Catalyst:
Co : 16.1%, Mn : 27.9%

Cu 95.2%, Ni 96.7%, Co 90.1%, Fe 62.9%, Mn 1.2%
Achievements

- Development of economical and environmentally friendly process
- Process development of high recovery of valuable metals (Cu, Ni, Co, Mn, Mo)
- Efficient treatments and utilization of process wastes
- Basic study to recover REE
- Pilot tests (Pro : 2 ton/day, Hyro : 200kg/day)
- Conceptual engineering design
Collaboration works with Industry

DS Metal → SNNC

SungEel HI Tech → LS Likko Copper
Manufacturing Process of Fe-Ni (SNNC)

Capacity: 3.6 million ton Ore
Manufacturing Process of Si-Mn (DB metal)

Ore, cokes, dolomite, silica
LS-Nikko Copper is the global leader with the world-best metal producing technology. Since Janghang refinery’s launch in 1936, LS-Nikko Copper has contributed in Korea’s industrial development and taken lead in “resources-rich Korea” through strengthening metal recycling and overseas resources development projects.

Cu product capacity : 600Kt
SungEel HiTech

- Recycling of Li ion battery
- Products: Co, Ni, Mn, Cu, Li

Solvent extraction system
Thank for your attention