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Which Technology could be suitably applied for the Remediation of Deep-Sea Mining Tailings?

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1. Background / Objectives

Remediation technologies for deep-sea mining tailings were mainly evaluated in this research, in order to derive candidate technologies for the future development of practical remediation technologies required for commercial deep-sea mining to respond to strengthening of international marine environmental standards. Polymetallic nodules which were collected at the Clarion-Clipper zone in Pacific Ocean consist of mostly of inorganic materials such as manganese(Mn, 61.0%), silicate(Si 10.3%), iron(Fe, 5.57%), heavy metals and other tiny elements. It is assumed that deep-sea mining tailings may be slurry mixed with fine solid materials having a particle diameter of several tens to 100 µm which are originated from crushing of polymetallic nodules and liquid substance produced from selection process on vessel connected with lifting and collecting procedure. Fine particles as well as harmful components eluting from deep-sea mining tailings may adversely affect marine environment including marine life. A new modular remediation treatment system in which physical separation and chemical treatment are repeated several times in a single treatment flow should have to develop in order to overcome various limitations (space, energy, process water, vibration, corrosion, weather conditions et cetera) at sea area.

Keywords: Deep-sea resources, polymetallic nodules, mining tailings, remediation, candidate technologies

2. Approach / Activities

Polymetallic nodules were collected using free fall grab and box corer at the Clarion-Clipper zone (Location: 131°22.68′W~131°17.22′W, 10°27.3′N~10°32.7′N) of Pacific Ocean in March 2018. Collected polymetallic nodules were dried naturally in research vessel during survey period. After survey cruise, dried polymetallic nodules were stored at room temperature in a laboratory. Dried polymetallic nodules were initially crushed by a jaw crusher and secondly crushed by a ball mill. Dried polymetallic nodules were initially crushed by a jaw crusher and secondly crushed by a ball mill. Then crushed nodules were separated as three particle size (larger than 63 µm, 20~63 µm, smaller than 20 µm) using two vibratory sieve shakers (Analysette 3 pro, Fritsch, Germany). This procedure was repeated several times. These materials which prepared with three particle size were used as samples in this research.

Figure 1. Shematic diagram if deep-sea mining process and collecting area map of polymetallic nodulers

The constituents of samples were determined by X-ray fluorescence spectrometer (XRF-1800, Shimadzu, Japan). The material structures of samples were evaluated by scanning electron microscope (SEM) (S-2400, Hitachi, Japan). Carbon components of samples were determined by total organic carbon (TOC) analyzer (TOC-Vcph, SSM, Shimadzu, Japan). Heavy metals were determined by inductively coupled plasma-mass spectrometer (ICP-MS) (Thermo X series, Thermo-Fisher, USA). The recovery ration of heave metals was also verified using standard reference materials, MESS-3 (National Research Council, Canada). The magnetic property of samples was evaluated by magnetic property measurement system (MPMS-7, Quantum design, USA). Besides, all chemical reagents used in this research were extra pure (EP) grade.

3. Results / Lessons Learned

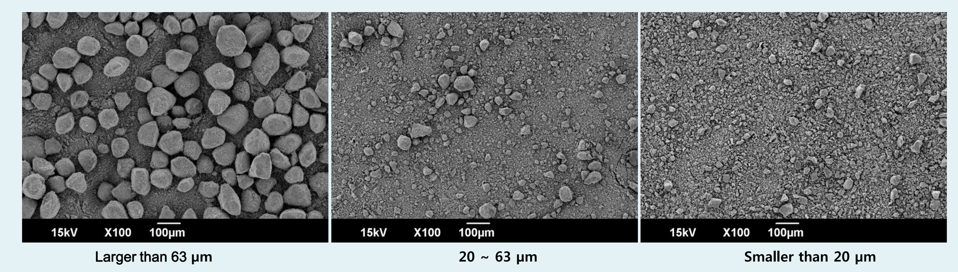


Figure 2. Materials structure of sample at each particle size

3.1 Characteristics of sample

Table 1. Constituents of samples at each particle size

Element	smaller than 20 µm	20~63 µm	larger than 63 µm	Nodules (Kuhn et al, 2017)
	Content (%)			
Mn	27.1	30.5	28.1	27.0
Si	13.2	10.3	11.4	
Fe	8.66	5.57	6.91	8.00
Na	3.00	3.59	3.53	
Al	4.04	3.07	4.11	
Ni	2.80	2.96	3.53	1.40
Ca	3.06	2.71	3.32	
Mg	3.00	2.65	3.61	
Cu	1.98	2.59	2.61	1.30
Cl	2.03	2.01	1.68	
K	1.76	1.85	2.05	
Ti	0.581	0.475	0.415	
Co	0.375	0.399	-	0.20
Zn	0.296	0.348	-	
P	0.391	0.302	0.363	
S	0.259	0.264	0.317	
Ba	0.509	-	-	
Sum	73.0	69.5	71.9	37.9

Organic contents of samples

TOC = 0.33%
(> 63 µm, 20~63 µm, < 20 µm)

Table 2. Heavy metal concentration of sample at each particle size

Specification	Al wt%	Fe wt%	Cr mg/kg	Ni mg/kg	Cu mg/kg	Zn mg/kg	As mg/kg	Cd mg/kg	Pb mg/kg
Larger than 63 µm	1.89	3.13	8.62	15,004	13,606	1,578	43.3	24.3	247
20 ~ 63 µm	2.38	4.17	7.85	15,131	12,932	1,462	55.3	18.0	254
Smaller than 20 µm	2.72	5.53	12.4	13,471	10,993	1,238	65.5	15.9	333

Table 3. Environmental standards for marine sediment remediation (KOREA)

Environmental standard, KOREA	Cr mg/kg	Ni mg/kg	Cu mg/kg	Zn mg/kg	As mg/kg	Cd mg/kg	Pb mg/kg
Level 1	80	23	24	200	9.0	0.68	50
Level 2	370	52	108	410	41.6	4.21	220

Table 3. Magnetic susceptibility of sample depending on particle size

Specification	Magnetic susceptibility(χ)
Larger than 63 µm	9.7×10^{-7}
20 ~ 63 µm	7.0×10^{-7}
Smaller than 20 µm	6.0×10^{-7}

Magnetic separation may not effective

Primary target materials: Ni > Cu > Cd > Zn
Secondary target materials: As > Pb

Affect on marine environment
Harmful contents in eluted liquid
Fine particles lower than 75 µm

3.2 Consideration of existing commercial remediation technologies

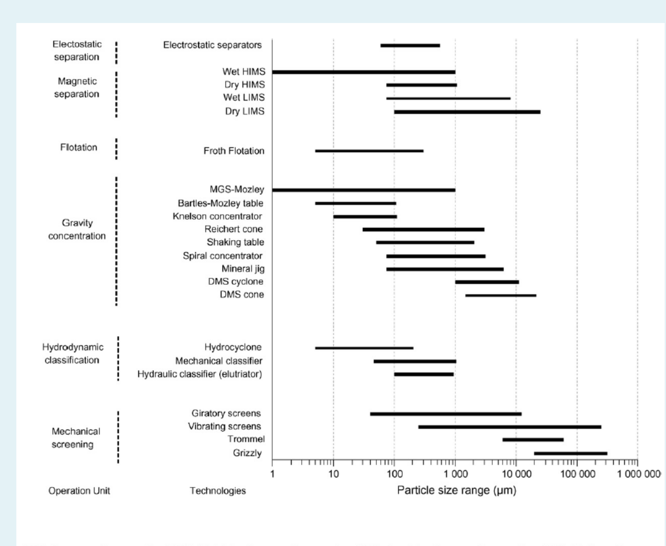


Figure 3. Feed particle size range for application of physical separation technologies
(Journal of Hazardous Materials, 152, 1-31, 2008)

According to the characteristics of target materials

Technology or reagents may commonly select
(Engineering Geology, 60, 193-207, 2001)

But, the remediation of deep-sea mining tailings is…?

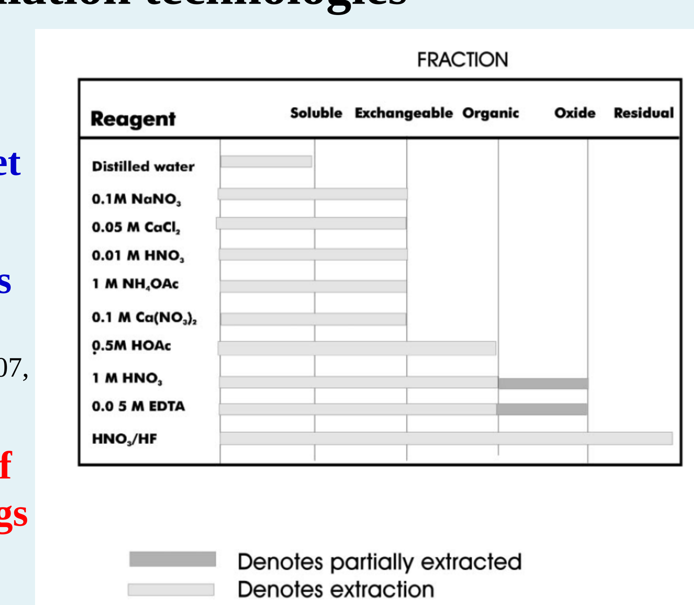
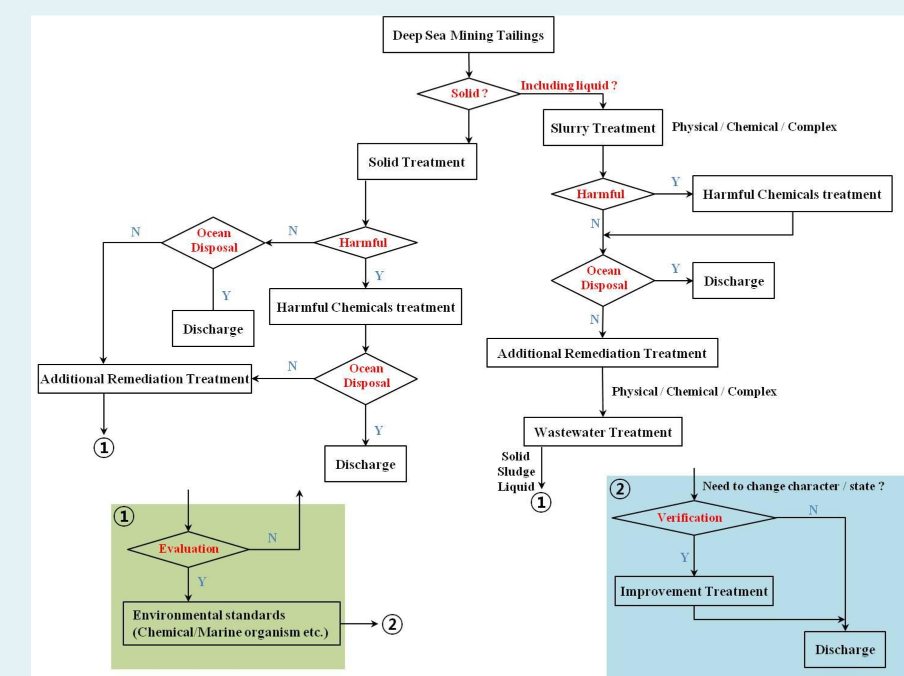


Figure 4. Feasibility of chemicals as extracting agents for different metal fractions
(Journal of Hazardous Materials, 85, 145-163, 2001)

Limitation of conventional remediation treatment in sea area, on-site
- Limitation of space (Surface area and height)
- Limitation of energy and process water
- Ocean weather such as storm or wave, vibration, rust due to salt
- Need to minimize discharge wastewater and reduce liquid of solid ratio (L/S)
- Need to make modular treatment system

3.3 Deriving candidate remediation technologies
- Evaluation more various deep-sea mining tailings and then make database
- Separation technology may need to develop and optimize for fine particles (75 µm)
- Chemical treatment may need to develop under mild conditions and reagent
- New modular treatment system may need to develop in a single flow
- New water treatment technology may also nee to develop (without settler or dewatering process)
- Remediation technology need to develop based on recent research results



Environmentally friendly additives, bio-surfactants,… ?

Figure 5. Concept of development plan for the remediation of deep-sea mining tailings

4. Conclusions

1] Since deep-sea mining tailings have fine particles and heavy metals affecting marine environment, these materials should have to be treated with appropriate remediation technology and then finally disposed in sea area.

2] A new remediation treatment system should have to develop in order to overcome the limitations of land-based treatment technologies consideration of on-site conditions.

3] There is no need to develop highly precise remediation technology in considering of required time, money and efficiency.

4] A modular treatment system which selectively separates and washes according to the degree of contamination and particle size need to be developed.

5] It is also necessary to develop a treatment technologies for improving the property of treated materials connected with remediation process, for safe ocean disposal.

In the near future, the actual development results of remediation technologies will be reported continuously for deep-sea mining tailings.

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