

# AN OVERVIEW OF THE INTEROCEANMETAL (IOM) DEEP-SEA TECHNOLOGY DEVELOPMENT (MINING AND PROCESSING)

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## ABSTRACT

In order to prepare a sound basis for mining technology IOM focused on analysis of existing opened practices and development of a conceptual design for mining system applicable for the IOM's exploration area. The comparison of alternative variants for assessment of technical requirements for basic components of mining technology was carried out. Development of system of the mining complex control included mathematical modeling of mining complex systems and computer simulations of control process. Computer simulations of the control process included assessment of effects of the marine environment on the mining complex, movement of the mining vessel and nodule miner and effects of the movement on the transport rise pipe length paid out, and riser pipe deformation. The laboratory tests have been carried out with purpose to estimate slip velocity and experimental verification of nodules vertical flow on selected lifting sub-system.

Based on the existing facilities in the IOM member countries the research on nodule processing technology included re-assessment of the variants of the technological schemes of hydrometallurgical, pyro-hydrometallurgical, acid and ammonia leaching routes. In addition, it was accomplished pre-feasibility studies based on the previously selected and partly optimized technologies as well as it was expanded the research in the area of non traditional directions for nodules treatment.

This paper outlines a brief overview of strategy and some results of IOM program for deep-sea development of mining and processing technologies.

## INTRODUCTION

The Interoceanmetal Joint Organization (IOM), an intergovernmental consortium certified by the governments of Bulgaria, Cuba, Czech Republic, Poland, Russian Federation, and Slovakia, was signed on 29 March 2001 a contract with the International Seabed Authority (ISA) for exploration of polymetallic nodule deposits in the area (75 thou. sq. km) situated in the eastern part of the Clarion-Clipperton Zone (NE Pacific).

In implementation of the 15-yrs plan of work for exploration, IOM carrying out comprehensive research and development studies in geology, marine environment as well as in the mining technology and processing of polymetallic nodules.

The main objective of the IOM activity during the first and the second five-year period (up to 2010) is delineation of nodule fields and identification of nodule deposits and reserves within prime areas that could be mined in the future. IOM has made considerable progress in geological exploration using multi-beam echo-sounder system, deep-tow photography survey

(digital format), bottom sampling and performed a huge amount of analysis of physical, mechanical and chemical properties of sediments and nodules.

Environmental study was focused on the collection of environmental baselines data on physical, chemical, geological and biological components of marine environment in the exploration area.

Research on development of mining technology included analysis and assessment of the existing nodule technology and development of a conceptual design for a future mining system.

The work on nodule processing involved the optimization of the existing technological schemes for extraction valuable components from polymetallic nodules, and development of the basic technological schemes for polymetallic nodules processing.

However, in accordance with the IOM's 15-yr plan of work for exploration efforts and investments for research on development of mining and processing technologies will be focused on the end of Phase 2 (2010 -2012) of exploration activity.

## **DEVELOPMENT OF ADVANCES MINING TECHNOLOGY**

### **An integrated model of nodule mining system**

In order to research and develop nodules mining technology the IOM strategy includes the following activities:

- pre-feasibility study based on existing mining technologies;
- development of a site-specific conceptual design;
- modeling and testing of the most important sub-systems and components;
- developing an engineering design of a pilot integrated mining complex and its *in situ* testing.

It is assumed, that the most essential requirement to development of deep seabed mining system is the technical and technological adaptation of equipment characteristics to geological, geotechnical and environmental conditions of the IOM exploration area.

We don't keep in view only relationship between mining systems parameters and particular conditions of nodule deposits, but we refer about relations among all components and parts joined in deep-sea exploration, exploitation, transportation, nodule processing and environmental impacts. Therefore, the IOM strategy for development of deep-sea nodule mining systems considers relations:

- existing information about ore exploitability conditions and state-of-the-art equipment;
- existing and proposing state of technical and technological development;
- competitiveness and patent protection;
- requirements of environmental protection.

Based on the world's practices and IOM countries experiences the conceptual design includes the basic principles of mining functionality and consists of complex units, subsystems and components (Fig. 1):

- mining vessel or floating platform;

- seabed collecting miner (nodule mining collector);
- buffer, platform temporary storage in front of vertical transport;
- control and management system;
- energy subsystem.

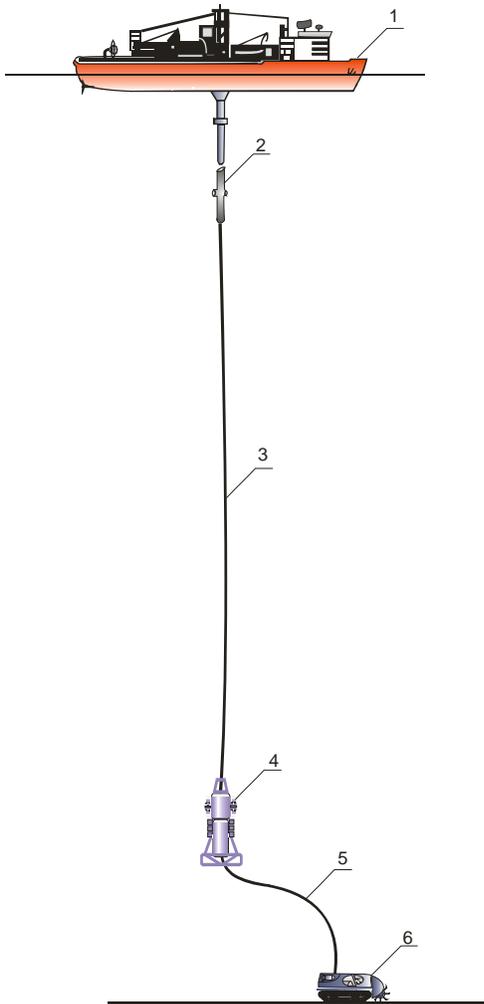


Fig. 1: Concept of nodules mining system

- 1 - mining vessel;
- 2 - buoyant elements;
- 3 - lifting pipe;
- 4 - buffer;
- 5 - flexible hose;
- 6 - self - propelled collector.

Development of advances mining technology included mathematical modeling of mining complex systems of production, ship and ocean transportation as well as computer simulations of integrated control process.

Computer simulations of the control process included assessment of effects of the marine environment on the mining complex, movement of the mining vessel and nodule miner and effects of the movement on the transport rise pipe length paid out, and riser pipe deformation (Fig. 2).

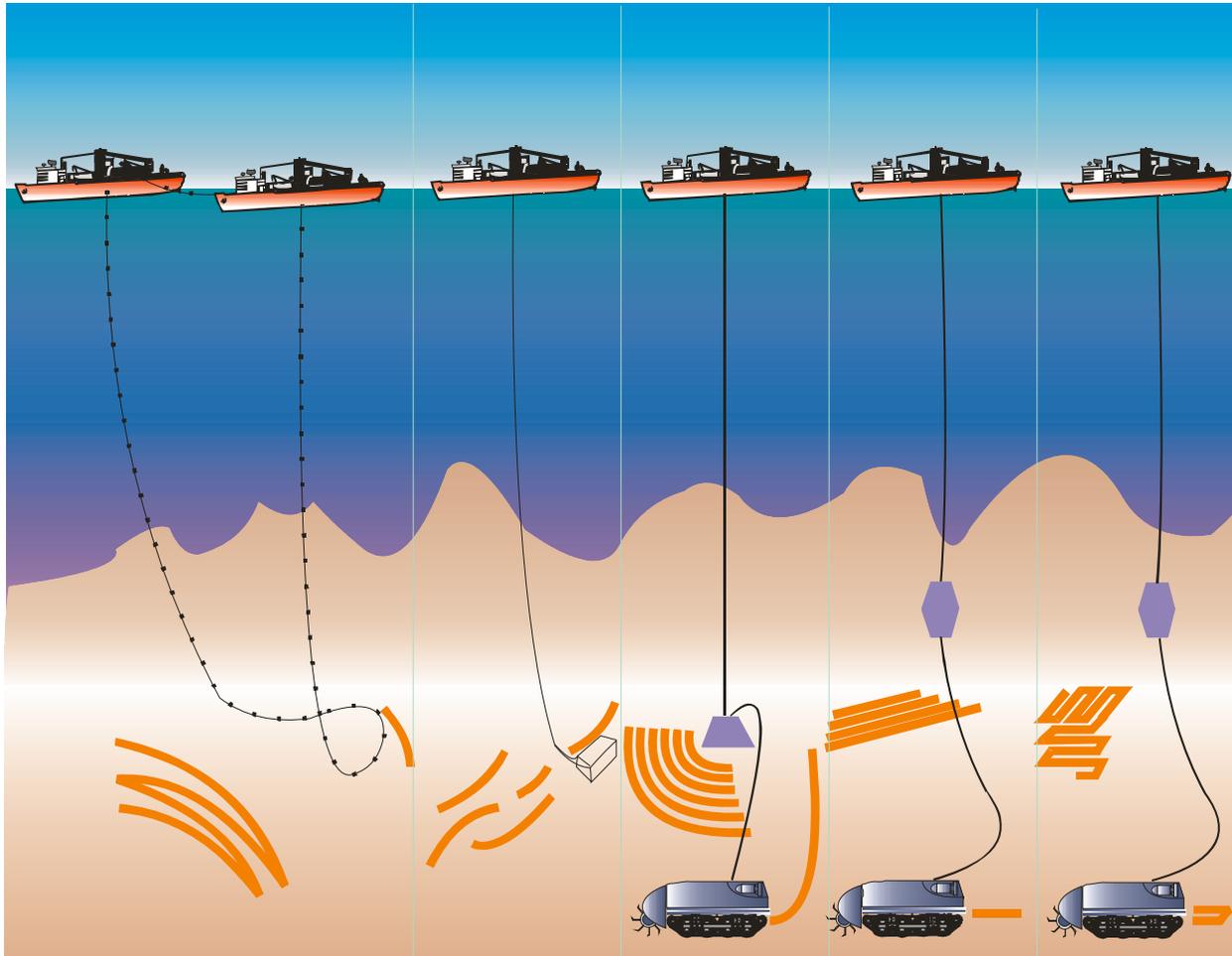


Fig. 2: Main principles of designing mining systems with mining paths

Preliminary results of the simulation showed that stress in the collection system riser pipes did not exceed acceptable levels; the riser pipe shape deformation depends mainly on mining vessel movement speed and can be reduced or controlled by horizontal forces applied at low speeds.

### **Nodule lifting subsystems**

The nodule lifting subsystem is targeted to realization these basic functions:

- the continuous vertical transport from sea floor to mining vessel;
- keeping the position of the mining collector;
- framework for power and communications channels bottom - surface.

Six various hydraulic lifting options were theoretical evaluated and suitable varieties were selected on the basis of the chosen criteria (Fig. 3.).

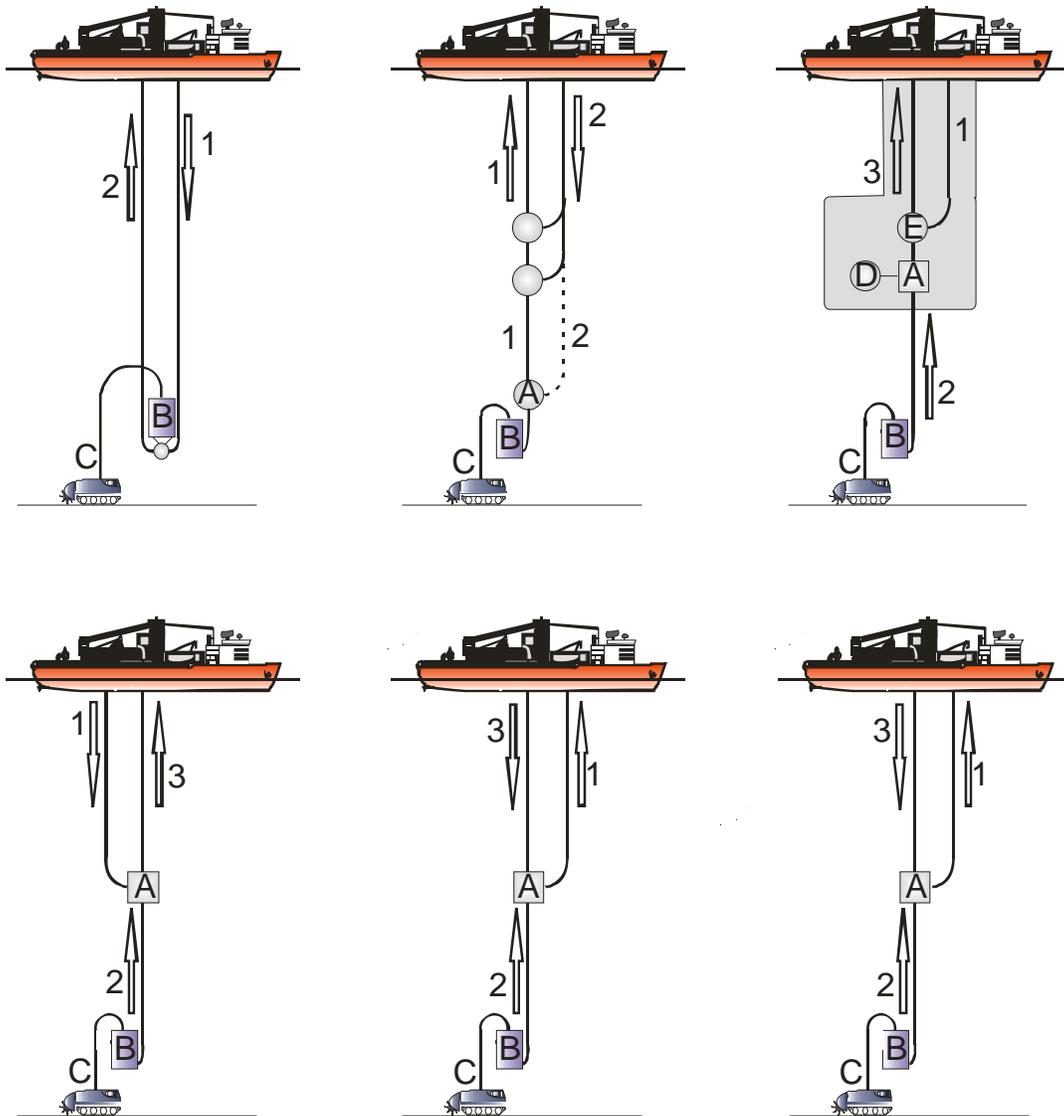


Fig. 3: Components of hydraulic lifting mining subsystems.

A - crusher, B - buffer, C - collector, D - discharge pump, E - lifting pump,  
1, 2, 3 - progress mixture direction

The investigations were conducted on an experimental stand specifically constructed for nodule and water velocity measurements at upward flow in the hydraulic laboratory in the Department of Water Engineering and Hydrotransport of the Agricultural University of Wrocław, Poland.

The mixture phase velocity measurements were carried out with application of radioisotopes using both natural and modeled nodules. The slip velocity values measured for 10-, 30- and 50 mm diameter nodules at the volume concentration 10 %. The investigations were carried out in a pipeline of 150 mm diameter that is of a presented diameter to be probably applied in ocean conditions.

The comparison of measured and calculated values confirms the assumed thesis that the different density of examined nodules may be the reason for the isotope differences of: 50-, 30-, and 10-mm diameters found during the isotope examinations. The different shape of natural and modeled nodules also constitutes the reason for differences. Modeled nodules have a shape close to a regular one, while all nodules have an irregular shape. Therefore, the resistance coefficient for these different shapes may differ significantly, which in turn is expressed by different values, both for natural and modeled nodules.

### Nodule collector subsystems

The selection of a miner construction was resulted from the next input conditions:

- the miner constructions scheme must respond to pilot test operations, to provide minimal changes to ensure semi-pilot exploitation in real mining condition;
- manufacturing, operating and technologic parameters to regard priority by the comparison of the miscellaneous characteristics of alternative nodule collector versions;

The nodule mining collector is composed of these main module parts (Fig. 4):

- undercarriage;
- collecting device;
- control unit.

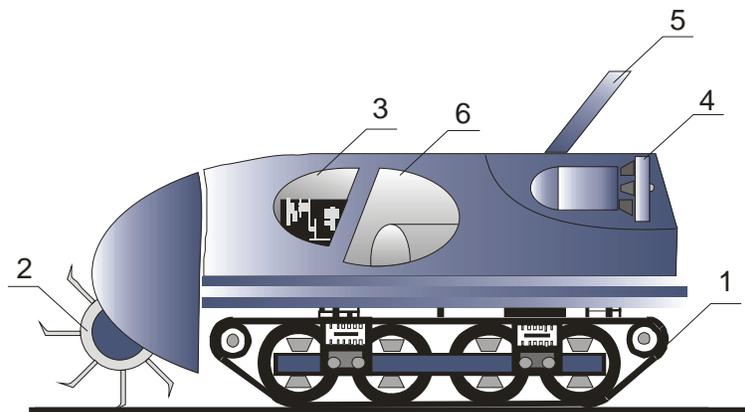


Fig. 4: Nodule mining collector

1 - caterpillar belts, 2 - collecting devices, 3 - operations and control equipments, 4 - power units, 5 - riser system, 6 - buoyant elements.

Distribution characteristics, associated with the seabed features, bottom topography, such as the relation of nodules with topography, morphology of the seafloor, nodule size as well as mine site type influence on the method of exploitation and the environmental impacts at the seafloor and in water column must be taken into account during the development of the collector.

To reduce mass of sediment swirled to up into the bottom near-water layer, to minimize sediment penetration, to minimize the transport of sediment; some of negative environmental effects also need to be taken in design conditions.

The approach with module collector construction makes multiple investigations with various types of working devices possible. The main operating mode must be automatic mode

cap minimal intervention to remotely program-controlled stirring. The flat nodule distribution demands constant touch of nodule collector with seabed bottom and synchronize competence to orientate oneself in workspace.

Collector properties, as maneuverability, controllability, stability, hurdles surmount, must to respond to deposits conditions and to enable adjustment of collector to variable exploited requests. Another function of nodule mining collector is carrier of buoyant elements and operating equipments for eventual: unloading, washing, sorting, crashing, grinding and nodule displacement to buffer. The collectors will affect in non-bearing floors, the carriages main function will ensure mobility and nodule collecting in large measure of variant interrelationships collector - seabed. Redistribution loading on carriage by different extracted nodule quantity and dynamic environs effects will specify the range of these variations.

### **Future plan**

Development of a conceptual design for a nodule mining system is in progress, due attention being paid to the prevailing geological and environmental at-seagoing research in the exploration area.

The IOM is presently planning to focus on:

- development the basic sub-systems and components of the mining integrated system;
- acquirement of *in situ* geotechnical and environmental data and information for development of nodule collector;
- development a preliminary project of a prospective mining system which should take into account geotechnical features of delineated nodule deposits within exploration area;
- developing experimental models of the basic sub-systems and components of the mining integrated complex, their modeling and testing in simulated seabed environment in laboratory or offshore conditions;

Regarding the costly innovation and time-consuming mining technology development IOM endorse interest in collaboration with other contractors.

## POLYMETALLIC NODULE PROCESSING

Based on the existing facilities in the IOM member countries, the following projects were identified for evaluation: pyro-hydrometallurgical, hydrometallurgical, acid and ammonia leaching technologies.

### Pyro-hydrometallurgical processing

That type of polymetallic nodule processing methods (Fig. 5) has been studied at the University of Chemical Technology and Metallurgy, Sofia, Bulgaria and Hutni Project, Bratislava, Slovakia.

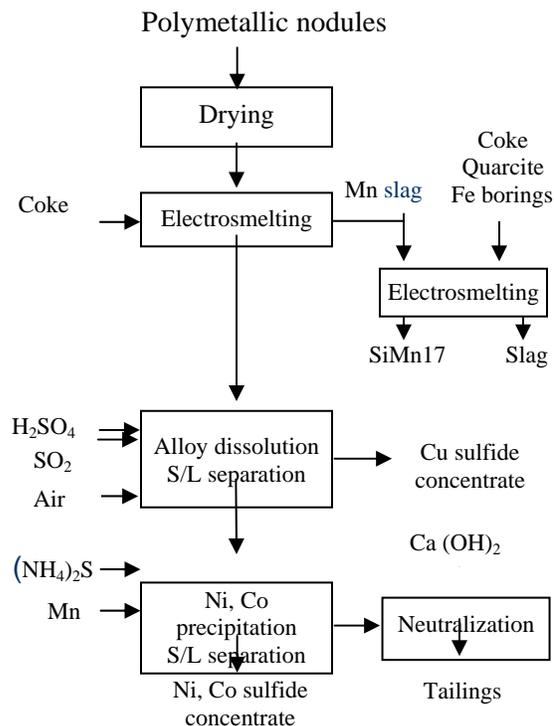


Fig. 5. A preliminary scheme of pyro-hydrometallurgical processing of polymetallic nodules

The „mixed” process scheme consists of two main parts:

a) pyro-metallurgical process with selective reduction of non-ferrous metals to a complex Cu-Ni-Co alloy and transition of the manganese and ferrous oxides to the slag phase with its subsequent processing to obtain silicomanganese alloys.

The high-manganese slag subject to processing contains 47% Mn, 1.07% Fe and 0.04% P; the complex alloy - 1.30% Cu, 15.2% Ni and 1.30% Co (with extraction rate of the main elements, %: Cu - 92, Ni - 93, Co - 89).

b) hydro-metallurgical processing of the complex alloy. It takes place in two stages:

- Selective dissolution in a solution of sulphuric and sulphurous acid. Ni, Co (partly Mn and Fe) pass into the solution while copper remains as a soluble residue of CuS (53% Cu).

- During the second process stage, sulphidic precipitation of the Ni-Co concentrate takes place (in the presence of oxygen and after neutralization)

The mixed, pyro-hydrometallurgical scheme is characterized by simple organization, affordable, non-expensive equipment and moderate investment costs, however, it is energy intensive to a certain extent - the relative power consumption per 1 ton of high-manganese slag is 700 kWh/ton. At the process optimization phase, solutions will be sought to reduce it using suitable reducers, process heat utilization, etc.

A preliminary technical/economic assessment was made of the developed pyro-hydrometallurgical scheme (Tables 1, 2 and 3).

Table 1

Annual commercial production and extraction of metals

Product	Silico-manganese	Cu concentrate	Ni-Co concentrate
Output, t/year	432 000	28 200	50 600
Mn Content, t	301 800	136	296
Mn Extraction, %	72.8	-	-
Cu Content, t	216	14 970	104
Cu Extraction, %	-	90	-
Ni Content, t.	104	840	14 800
Ni Extraction, %	-	-	84
Co Content, t	80	96	1 890
Co Extraction, %	-	-	79

Table 2

Raw material, feedstock, and energy consumption

Description	Quantity, t/year	Price, US\$/year	Amount, US\$/year	%
Raw polymetallic nodules	1 500 000	97.4	146 100	37
Other feedstock			94 693	24
Energy, including:			158 319	39
• Power, MWh/year	2 644 500	42 US\$/ MWh	111 069	
• Natural gas, m <sup>3</sup>	270 000 000	175 US\$/1000 m <sup>3</sup>	47 250	
TOTAL			399 052 000	100

Table 3

Operating costs for processing of 1 500 000 tones nodules

No.	Description, items	Cost, US\$	%
1.	Raw materials and feedstock	240 793 000	58,0
2.	Power and fuel	158 319 000	33,0
3.	Administrative costs	4 100 000	1,0
4.	Salaries	4 290 000	1,0
5.	Depreciation costs	23 800 000	6,0
6.	Other costs	2 700 000	1,0
7.	TOTAL	414 002 000	100,0

Tables 2 and 3 present the estimated cost of product output in the case of processing of 1 500 000 t polymetallic nodules. The prices of materials, electric power, fuels, etc., are as of 2001. The cost of the mined polymetallic nodules is assumed a priori to be a constant. Therefore, of all cost components, that of electric power and fuel has the highest variable weight- 33%. Its reduction is the reserve for improvement of the process scheme efficiency and will have the most significant impact on the final product costs.

### Hydrometallurgical processing

The hydrometallurgical nodule processing schemes are developed mainly at CNIGRI-Moscow, Russia.

Polymetallic nodule processing using sulphuric acid (Fig. 6) is based on manganese oxide reduction by means of sulphuric anhydride and formation of soluble manganese sulphate. A specific feature of the process developed is selective dissolution of the non-ferrous metals and manganese.

The process takes place at 70-80°C temperature and atmospheric pressure. The gases released during burning of sulphur or roasting of pyrite concentrates can also be used for extraction of the useful components from nodules (SO<sub>2</sub> 10-16%).

The product solutions containing non-ferrous metals, manganese and smaller quantities of other impurities are subjected to copper sulphate precipitation through introduction of activated sulphur powder and feeding of sulphuric anhydride into the reactor. Under these circumstances, a high degree of copper sulphide precipitation is achieved and, after its separation from the solution, Ni-Co concentrate is precipitated by introduction of powdered sulphur and metallic manganese.

The manganese contained in the Ni-Co concentrate is dissolved through its re-pulping in sulphuric acid solution. Thus, the whole quantity of metallic manganese passes into the solution with subsequent regeneration.

As a result of nodules processing by the sulphuric-acid method, commercial products with the following chemical composition are obtained: copper concentrate with copper contents 40%; Ni-Co concentrate - 20.8% Ni and 2.7% Co and Mn-concentrate with 62% Mn. The recovery of metals from the concentrates is: Cu - 92%, Ni - 96%, Co - 92%, and Mn - 96%.

The hydrometallurgical process developed is characterized by performance of the main operations - extraction, dissolution and production of the concentrates, at atmospheric pressure and low temperatures, without need for preliminary drying of the feedstock which improves their energy efficiency.

Based on the enlarged Russian laboratory results, the Slovak engineering company performed the pre-feasibility study. It was based on a scheme shown in Fig. 6.

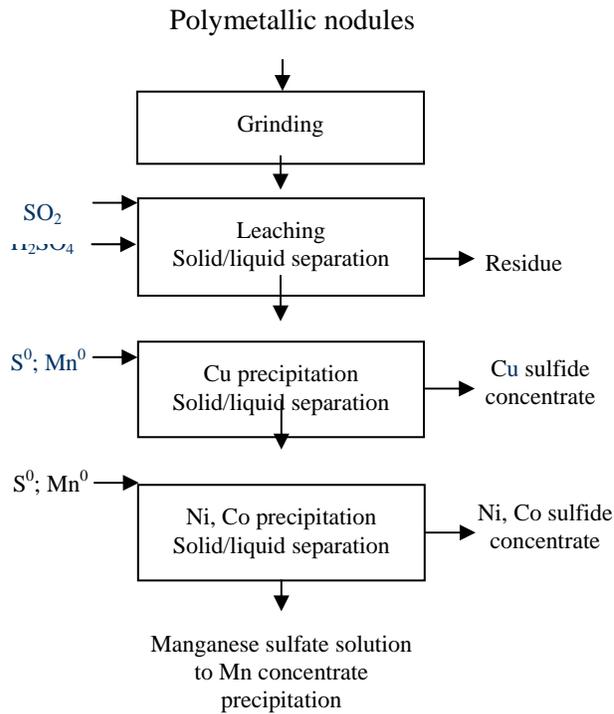


Fig. 6 A simplified scheme of n leaching using SO<sub>2</sub> as a reductant

The study's main boundary conditions were: 1.5 mil t nodules processed; battery limit restriction; the following metal recovery in the concentrates: 92% Cu (40% Cu in the concentrate), 96% Ni (20.8% Ni in the concentrate); 92.6% Co in Ni-Co sulfide concentrate (2.7% Co in the concentrate); 94.4% Mn (59.5% Mn in the concentrate); concentrate metal prices: 1 030 USD/t Cu in Cu sulfide concentrate; 3 325 USD/t Ni in Ni-Co sulfide concentrate; 18 000 USD/t Co in Ni-Co sulfide concentrate; 250 USD/t Mn in Mn oxide concentrate; and 75 USD/t ammonium sulfate as a byproduct; depreciation included; the assumed cost of 1 t dry polymetallic nodules equal to 97 USD at processing site; the basic case profit estimate is approximately 7 mil. USD per year. We are, of course, aware that refining the project will probably diminish the profit estimate.

### Acid and ammonia nodule processing technologies

Based on the research work carried out by Nickel research center in Moa, Cuba we have on hand two technological schemes, first for application in Moa plant, the second for application in Nicaro plant, both with preliminary economic estimation of the process. However, both processes suffer from bad pulp settling characteristic. The simplified schemes are shown in Figs. 3 - 4.

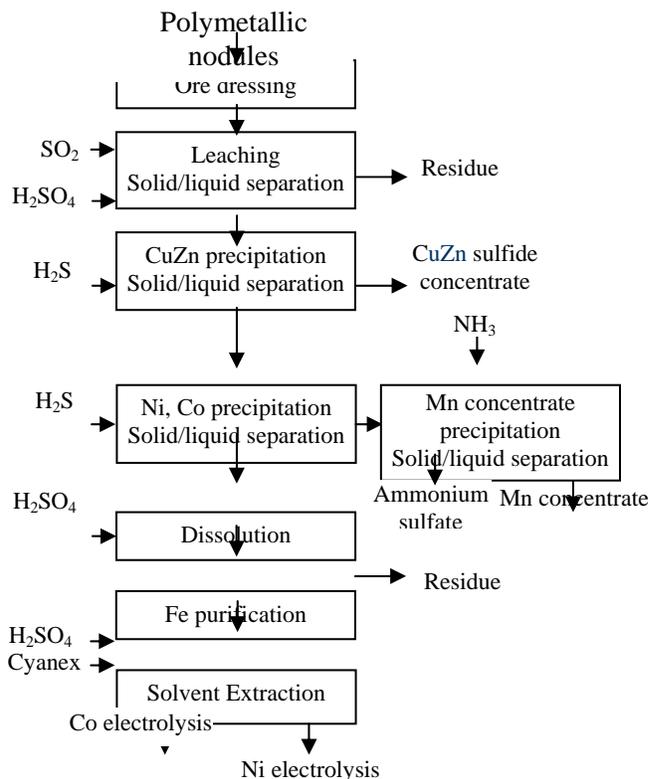


Fig. 3 Sulfuric acid and SO<sub>2</sub> leaching of PMN

Metal recovery for acid leaching is Ni 91,2 % as electrolytic Ni; Cu 98,7 % in sulfide concentrate; Zn 97,4 % as a sulfide concentrate; Co 85,6 % as electrolytic Co; Mn 92, 1 % as a Mn concentrate; for ammonia scheme is Ni 91,5 % as electrolytic Ni; Co 41,4 % as Eco; Cu 74,9 % as electrolytic Cu; Zn 79, 6 % as electrolytic Zn; Mo 75,3 % as a CaMoO<sub>4</sub>.

One variant of the sulphuric-acid process of metal extraction from polymetallic nodules is their conducting at high temperatures (over 100°C) and high pressures (autoclave methods). It was developed on the basis of technologies currently used for nickel ore processing in Cuba (Punta-Gordo).

The ammonia carbonate process schemes as an alternative to the sulphuric acid process were dropped from the planned activities of IOM due to the high energy consumption required for evaporation of the adsorbed and chemically fixed water in the nodules during their reduction at a temperature of 600°C.

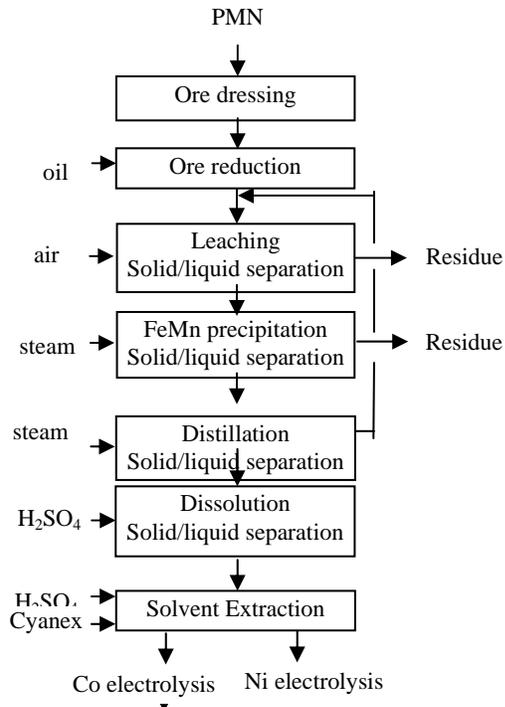


Fig. 4 Ammonia ammonium carbonate leaching (adapted Caron process)

Along with the studies of the nodule processing technology schemes and their comparative technical/economic assessment, IOM started also research on the potential regions provided with suitable nodule processing plants and infrastructures. The production capacities (mainly pyro- and hydrometallurgical technologies), the infrastructure (ocean and river ports), and other factors on the territory of South-East Europe were investigated.

### Perspectives

IOM research in nodule processing technology is one of the four main directions of activity during the second five-year program (2006-2010) approved by the ISA. In accordance with the IOM long-term program the main part of IOM research is directed to the pyro-hydrometallurgical and hydrometallurgical processing methods, however as a whole they will include:

- improvement of the hydrometallurgical polymetallic nodule processing;
- improvement of the pyro-hydrometallurgical polymetallic nodule processing;
- preparation the input data and the technology selection for pilot plant experiments;
- analysis of existing plants capacities and estimation of their capability for industrial nodule processing;
- assessment of environment impact arising from nodule processing and the development of technologies using polymetallic nodule processing for solution of environment protection problems;

- development of the new fields for polymetallic nodule application to improve the processing efficiency and/or extraction the valuable components.

As contractor with ISA, IOM suggest that cooperation among contractors and other stakeholders in the field of nodule processing technology need to be more efficiently activated. In first step we do see opportunities for collaboration in the methodological aspects of building a valuable metals market database, in providing a methodological background for procedures of developing and evaluating the economic side of projects prepared as well as in developing new application areas. We would like to contribute to that advancement.

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