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Mineral

Future Trends of Deep Sea Bed Mining Technology

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Abstract: The present status of deep sea bed mining technology for polymetallic nodules has been critically examined in light of its history of development, the UNCLoS (the United Nation Convention on the Law of the Sea) regime and the current trends in research. The critical technologies have been highlighted and the need for system integration underscored. The deep sea bed environment and the engineering challenge were presented and the necessary features of the deep sea bed mining system for commercial mining was analyzed. The key accomplishments, problems and future trends in research in the development of the mining system are also discussed. Finally, it points out that the technology gaps can be filled by the time commercial mining is undertaken as a result of market conditions in its favor.

Key words: deep sea bed mining; UNCLoS; TIS (Total Integrated System); polymetallic nodules; mining system

1 Engineering Challenge and Environmental Concerns

From the voyage of English Challenger in the Atlantic in 1873~1876, when for the first time the 'dark brown rock like nodules' containing iron and manganese littering large areas of the deepest part of the ocean floor were discovered, mankind has come a long way to make the economic exploitation of these nodules a distinct possibility in the early half of the 21st century. With steady development of technology and occasional breakthroughs, the deep sea bed exploration has conclusively established the polymetallic nodules as a significant mineral resource rich of Mn, Cu, Co and Ni in the near future, and has given the depletion of land based resources. In the meantime, the first pilot mining tests in 1978 (by OMI of US, Japan, Canada and Germany in the Pacific recovering 800 t of nodules from a water depth of 5500 m) and the subsequent tests (by OMA and OMCO in 1978) have conclusively established that the exploitation of this resource is technically feasible, though will require further significant progress in technology.

One should say that it is feasible to mine the polymetallic nodules from a purely technological standpoint. But presently it is impossible to do so economically. The reasons are twofold. First, the nodule mining is not profitable at the current price of extracting the metals from them even with fully developed and efficient technological means (achievable in the foreseeable future). Secondly, even if the altered price situation favors nodule mining today, the development of our technology still has a long way to go before serious problems can be solved and productionised. The R&D (research and development) and SD (sustainable development) in mining technology, therefore, must be developed continuously, which is now happening around the world.

Deep sea bed mining is a challenging frontier area of Ocean Engineering for several reasons: the marine environment is at its hostile best; the time range of operation is large (several years); the location is at great distance from shore; long term climate forecasts are unreliable and difficult to get; the mining system mobile; mining rates (several hundred tons/ hour) too high for economic viability; operational depth too large to fall back on previous experience; and high pressure environment difficult for survival of the components of any engineering system. Added to this are questions of redundancy and reliability of the system and its components to withstand long service hours (say 3000 h) between maintenance. Every aspect poses engineering challenges in design, construction, maintenance and economics of the mining system.

Furthermore, the development of the various technologies going into the mining system and the system itself must be in tune with the spirit of UNCLoS. This means a system 'as clean as possible' and ensuring the deep sea environmental security in the long run. At present, knowledge and understanding of the deep sea environment and ecosystem are poor, and the researches started only recently. The effect of mining on the environment, especially on deep sea sediment, has been and being tested in several environmental experiments, such as DISCOL (disturbance-recolonization experiment, Germany, 1989~1994), BIE (the Benthic Impact Experiment, USA, 1993, Japan, 1994, IOM, 1995), NaVaBa (Natural Variability of Baseline, China, 1996~2000), *etc.*, which have thrown up more questions than answers, there is inability of the present day knowledge to explain the observed facts. Given this state of science, it is prudent to minimize disturbance by a mining system to the sea bed sediment layer sustaining the ecosystem as much as possible. This approach is essential to the development of the mining system, both at pilot test and commercial production stages.

2 Desirable Features of Deep Sea Mining Subsystems

General requirements of a mining system must have the following parts (shown in **figure 1**):

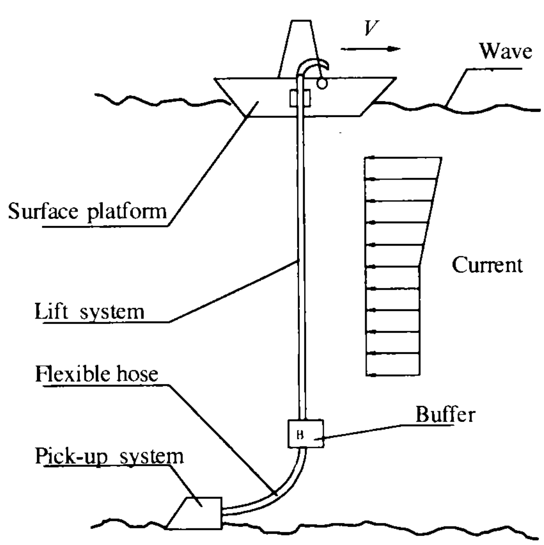

Figure 1 Mining system model

(1) A surface platform, either a ship or a semi-submersible floating platform, required to: (a) deploy the nodule pick-up and lift system to the sea bed, (b) carry out some on-board processing, *e.g.* their separation from sediments, (c) store nodules, (d) support the power plant for mining, (e) support control, communication and instrumentation equipment for the mining system [1].

(2) A technique, to pick-up the nodules from the sea bed, *i.e.* the pick-up system.

(3) A technique, to transport the picked-up nodules to the surface platform, *i.e.* the lift system.

(4) A method, to separate the mined nodules from sediment-water mixture on board the platform.

(5) A method, to discharge the separated sediment-water mixture back to the sea.

(6) A power plant, for the deployment, pick-up and lift systems.

(7) A deployment procedure with necessary on-board equipment, to deal with the pick-up and lift systems.

(8) A control and communication system, on-board to execute nodule recovery per plan at desired rates.

These are probably necessary features of any sea bed mining system. Considering some desirable features of such a system, these are:

(1) An efficient pick-up system, crucial for four reasons: First, the pick-up rate at operating locations must be as high as nearly 100%. Secondly, its movement must be such as to recover nodules from the entire area without leaving any area patches or strips with totally unrecovered nodules, however small they may be. This is referred to as 'sweeping efficiency'. Both these features (*i. e.* high pick-up and sweeping efficiency) see to that there is no resource lost. It is well to keep in mind that unthorough use of resources is an unwanted sacrifice in income and future wealth which is not permitted. Thirdly, the pick-up process must be 'as clean as possible', meaning to minimize disturbances to the sea bed sediment layer, which is impossible to eliminate completely, however, should be limited to the maximal extent possible. This can be done if the collector picks up nodules without much sediment on and if there is found a feature of sediment separation on the collector (*i. e.* very near to the seabed). This will ensure that only a small amount of sediment is carried up while most of them are released very close to the seabed, facilitating quick resettlement; Fourthly, the power requirement of the pick-up system must be minimal.

(2) An efficient lift system. Once the nodules are picked-up, the major task is to transport them to the surface platform, 5 to 6 km up vertically. The largest part of the power requirement of the mining system is to carry out this function, and its minimizing is therefore an important objective.

(3) Reliability of the recovery (*i.e.* pick-up and lift) system. The need for reliability of any ocean engineering system cannot be overemphasized. There are two main reasons for this in the context of mining. First, a commercial mining system requires long time of uninterrupted operation (say 3000 h) between maintenance. The requirements of a pilot scale system can be much lower, however. Even then it is sufficiently large,

because, from the known data on economy of scale, the mining volumes need to be very large, about 3 million tons/year at one site. This turns into one or two mining installations with several hundred tons/hour (say 300 t/h) recovery rates. To achieve such high rates, high reliability of the system is required to avoid breakdown and costly (both in time and money) repair and hence loss of production. Secondly, a commercial mining system must be designed for several years (15 to 20 years) of operation in deep sea location at great distances offshore covering about 20 to 40 000 km^2 of area in this period. Such a long operational life for an essentially floating system (*i. e.* one which is not anchored to the seabed) in a hostile environment consisting of winds, currents and waves is a major engineering challenge. To date, in all ocean engineering activities, namely exploration of oil and gas, deep sea dredging, sea transportation etc., a floating system has never been used for such a long time. An exception is probably the floating OTEC (ocean thermal energy conversion) platform, which however, is stationary. The mining surface platform must have all the mobility of a ship as it is supposed to cover a large geographical area. The design of floating systems has always been such that they require frequent docking for maintenance. The recovery process of offshore oil and gas is always done by bottom supported structures (both fixed and compliant), which are anchored to the sea bed and are typically designed for a long life span (say 20 years). Therefore, floating systems for long continuous service life in sea require special attention to their reliability.

(4) A reliable and sophisticated underwater (UW) control and communication system. The pick-up and the lifting systems need to be controlled and their instrumentation is supported by this onboard system. UW communication is a less developed area and requires high reliability for continuous operation.

3 Accomplishments, Problems and Future Trends in Research

The key accomplishments, problems and the current and future research trends in the development of the mining system will be discussed and why commercial mining is not yet technologically possible will then be answered.

Deep ocean mining is a frontier area of technology characterized by its broad interdisciplinary nature. The prospecting and exploration field techniques are: (1) gravity, magnetometric observations and measurement; (2) bottom and sub-bottom acoustic profiling or imaging without the use of explosives; (3) mineral sampling of a limited nature such as those using either core, grab or basket samplers; (4) water and biotic sampling; (5) meteorological observations and measurements, including the setting of instruments; (6) hydrographic and oceanographic observations and measurements, including the setting of instruments; (7) sampling by box core, small diameter core or grab sampler, to determine seabed geological or geotechnical properties; (8) television and still photographic observation and measurement; (9) shipboard mineral assaying and analysis; (10) positioning systems, including bottom transponders and surface buoys. Furthermore, its development to date has largely been a result of international cooperation in a consortium mode. The engineering challenge in the design and construction of a commercial mining system emanates from three principal sources: (a) the system operates in most extreme environment known to man, namely, strong wave, current and wind forces at and near the ocean surface and extremely high pressures (50 ~ 60 MPa) and low temperature (1 ~ 4℃) near the sea bed; (b) the system is highly cost sensitive, with its success depending much upon energy and recovery efficiency; and (c) the system must have an environment conscious design. All these three aspects require innovative engineering solutions at their best.

As discussed earlier, the mining system consists of several subsystems (mining system under development in China, shown in **figure 2**). Their integration,

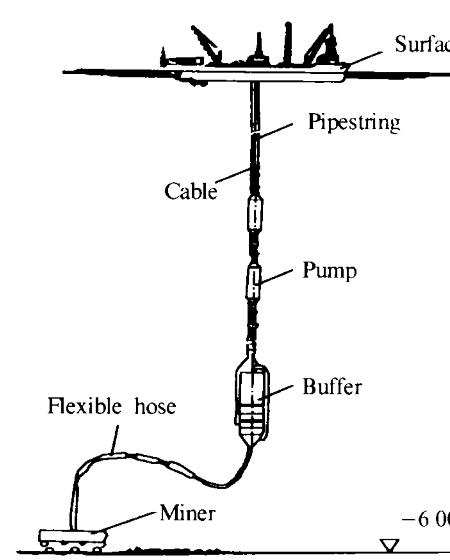

Figure 2 Mining system under development in China

given the abundance of nodules and the wave climate and water depth, is a key task, which ultimately decides the cost effectiveness. The concept of Total Integrated System (TIS) consisting of the modular design of subsystems is a current area of research [2]. The computer simulation model of TIS will go a long way in optimizing the cost and making realistic performance projections. The dilemma of site-independent versus site-specific designs can be resolved by this model, their relative cost effectiveness also can be estimated.

At the subsystem level, the design for extreme environment is crucial. This means that several conceptual design alternatives must be considered with promising ones among them tested in the laboratory (some using scaled down models) and predictive computational models developed and perfected in light of the experimental results. Development of new experimental techniques and facilities are required for this. The environmental aspects of the subsystem are also important at the conceptual design level and their experimental verification crucial. At the component level, the design for high pressure and its experimental testing (in pressure chamber) and design for severe wave climate and its experimental testing (in wave tank and flume) are the main tasks. Also, corrosion and erosion of the components have to be cared by design as well as material selection. All these are being actively pursued at many places.

Two most important subsystems of the TIS are the collector and the lift subsystems. New alternatives of the collector vehicles are still being proposed [3] and some well-known configurations being tested [4] for improving their performance. Close to 100% pick-up rate has been claimed [5] and is also the sweeping efficiency, even at the laboratory scale. Less than 1.5% sediment content in the picked-up material has been achieved in experiments [5], a significant result from the point of view of minimal disturbance to the sea bed sediment layer. The maneuverability of collector vehicle has also improved significantly. However, more pilot tests are required to confirm the laboratory results. Reliability of collectors is still solved unsatisfactorily. The design of hydraulic pumps for the lift system is still under development and basic studies on the lifting parameters are in progress [6]. Research on the determination of the frictional factor for the slurry and the optimum flow velocity of slurry is important in optimizing the power requirement of the lift subsystem. This depends on the sizes of the nodules in the slurry and this in turn will affect the design of the crusher mounted on the collector vehicle.

The capability of UW repair is important for a mining system, especially for the pipe-string. The precision navigation of the collector as well as the surface platform depends on new developments of UW communication links, an area still under active research. Such links will facilitate the use of sonars, UW cameras and other instruments on the collector vehicles in a reliable way.

In years to come, the developments in materials technology, microelectronics, computers, sonar, lasers and fibre optics will affect the performance of the mining system [7].

4 Conclusions

Deep-sea bed mining of polymetallic nodules will become a reality in the near future. Though present technology is not yet quite ready for the task, it is being actively researched to meet the future challenge. The perceptible slackness in the progress of technology seems to be due to the unwillingness to allocate funds beforehand to its development, given the situation that commercial mining in any case is not feasible purely due to the market considerations at present. It can be safely said that as the market conditions favor commercial mining, the existing gaps in technology will be filled and mining will be undertaken. It is hoped that the international community will live up to this challenge when its time comes.

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