# Developmental tests on the underwater mining system using flexible riser concept.

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## ABSTRACT

**An underwater mining system with a crawler based mining machine and a flexible riser system has been conceptualised for manganese nodule mining. The flexible riser system with a single positive displacement pump mounted on the mining machine is different from the rigid riser concepts of the seventies where multiple pumps are mounted at different levels along the riser. The system has been tested for mining operations at 410 metres water depth. Four tests were carried out on this system in the Indian seas. The paper discusses the flexible riser concept, details of the tests carried out and results obtained. Specific details of pumping and maneuverability tests carried out are discussed. Based on results from the tests enhancements proposed for future deep sea mining systems are also discussed**

## KEYWORDS

Sand mining system, underwater mining vehicle, crawler, flexible riser.

## INTRODUCTION

Deep sea mining of minerals like manganese nodules has been one of the challenging tasks facing ocean engineering. The nodules occur in the ocean floor at 5000 to 6000 metres depth. The mining machine / vehicle has to move on the ocean floor of very low bearing strength of the order of 50 $g/cm^2$, encounter gradients and obstacles, and selectively mine nodules with minimum environmental disturbance. The entire system must be capable of being deployed and retrieved easily and be reliable, as underwater maintenance will almost be impossible.

Most of the existing deep sea mining concepts are based on the tests carried out by various consortia active in the seventies (Chung, Whitney and Loden 1980; Brink and Chung, 1981; Chung, 1996). The systems had either a self propelled nodule collector (Chung 1996) or a towed collector (Heine and Sung, 1978) which collects and pumps nodules from the ocean floor to the lifting system, either directly or through an intermediate storage buffer unit. The lifting system has been either hydraulic or air-lift. Hydraulic lift systems had multistage centrifugal pumps installed at three different depths (Kuntz, 1978; Chung and Tsurusaki, 1994). In the case of airlift systems, compressed air was injected at intermediate depths and the solids were lifted up as a three phase mixture. Hydraulic lift systems had problems due to wear in the impellers. Maintenance of these systems was also difficult. The performance of the air-lift system was much below expected levels. Deployment and retrieval of the heavy pipeline was also very difficult and time consuming. Further those systems were highly cost intensive.

India has been allotted a mining site in the Central Indian Ocean Basin (CIOB) by the International Sea-bed authority and is keen on developing technologies to mine manganese nodules. A joint collaborative programme involving National Institute of Ocean Technology, (NIOT) India and Institut für Konstruktion (IKS) of University of Siegen, Germany was initiated to develop a deep seabed mining system with a crawler and a flexible riser system. In the first phase it has become essential that the system be proved in shallow waters before extending the same concept to deep seas. Hence the flexible riser system was developed and tested in the Indian seas at 410 metre water depths. Four tests have been carried out on this system.

## FLEXIBLE RISER SYSTEM

The flexible riser system (Grebe, 1997) is one of the novel deep sea mining systems being developed after the Law of the Sea treaty (UNCLOS -III) became effective as of 1994. A schematic diagram of the flexible riser system is shown in figure 1. The main subsystems of the flexible riser system are: the underwater mining machine / vehicle, the flexible riser system, launch / retrieval systems and mother station. A crawler based underwater mining machine collects the nodules as it moves along the ocean floor. The underwater mining machine is self propelled and remotely controlled. A special pick up and sieving device collects nodules of 20-100 mm size, sieves off the sediments and transfers the nodules to a screw crusher through a high angle stepped belt conveyor. The nodules are crushed to less than 30 mm size and pumped to the surface by a positive displacement pump. About 3-4 mining machines will be connected to one mother station. From the mother station the nodules will be transferred to a barge/ore ship.

The presence of multiple mining machines, flexible riser system instead of rigid riser system and a single positive displacement pump instead of multiple centrifugal pumps are the main differences of this system when compared to pipelift systems. The complete system has been discussed in detail in Handschuh et al (2001)

## DEVELOPMENT PHASES OF THE FLEXIBLE RISER SYSTEM

The flexible riser system has been proposed to be realised in three phases :

- First phase of validation of the flexible riser concept at 400-500 metres water depth for sand mining operations.

- Second phase of validation of nodule collection pick up and crusher systems using underwater mining machine developed in the first phase.
- Third phase of validation of the flexible riser concept for manganese nodule mining operations in the Central Indian Ocean Basin using one mining machine and other subsystems.

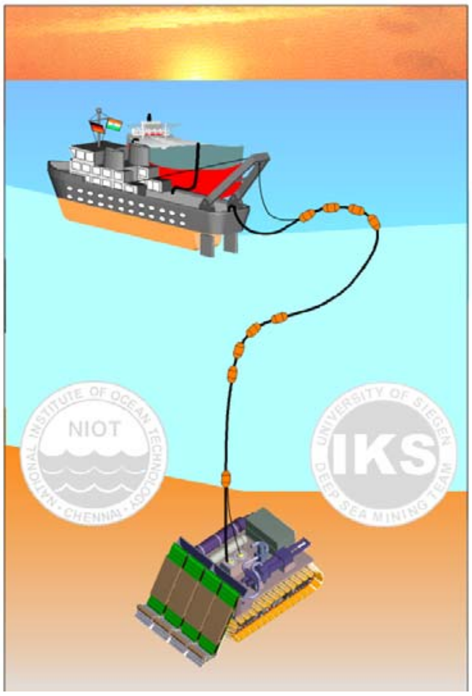


Fig. 1 Underwater mining machine and flexible riser system for manganese nodule mining

The first phase of validation of the flexible riser concept has been carried out in the Indian seas. The details of the system are presented in Ravindran et al. (1999) and Deepak et al. (1999). The schematic diagram of the system is shown in figure 2. An underwater mining vehicle was designed and developed which can work on soft sea bed. The crawler has a special track belt with involute teeth to compact the bed during motion (Rehorn, 1994). The crawler vehicle has a manipulator arm with a cutter to sweep the seabed and mine sand and a positive displacement pump to deliver the sand slurry to the mother ship through a flexible hose. The main drives of the crawler are hydraulically operated. The crawler vehicle has transducers for measurement of velocity, drum speed, heading, sand concentration etc. and has a closed loop control for speed, heading and slip (Atmanand et al., 2000). An umbilical cable with an outer steel armour carries the weight of the crawler vehicle during launching and retrieval.

The cable has copper conductors and optical fibres for power and data transmission respectively. During launching floats are attached at appropriate locations to enable the flexible riser obtain S-shaped profile at the bottom as shown in figure 2. The cable and hose are attached at regular intervals to ensure that both behave as a single unit. On reaching the sea floor mining operations can be started after obtaining the S shaped profile.

## DEVELOPMENT TESTS ON THE FLEXIBLE RISER SYSTEM

The developmental tests on the flexible riser underwater mining system was carried off Goa coast in the *Ocean Research Vessel Sagar Kanya.* Four tests have been carried on this system so far. The system has been designed to carry out launch and retrieval operations from normal ships without dynamic positioning systems up to sea state of 2.

Due to bad weather conditions, difficulty was experienced in launching as well as retrieval operations during the first two tests. Based on the experience it was decided to incorporate dynamic positioning system and a launch platform for the future mining systems for nodule mining. To position the ship for subsequent trials it was decided to use two tugs.

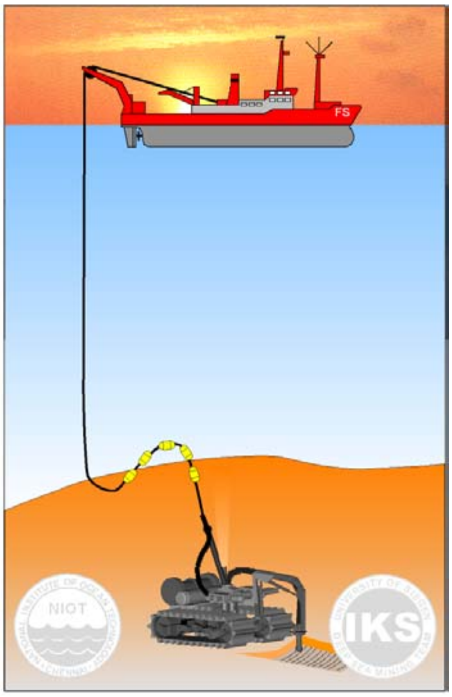
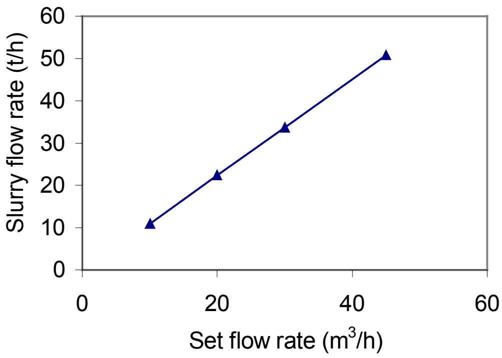


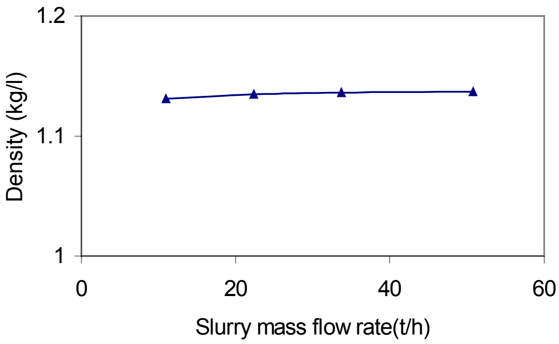
Fig. 2 Underwater sand mining system for the first phase of validation of the flexible riser concept

| | |
|---|---|
| **Underwater Mining Machine** | |
| Overall length | - 3160 mm |
| Overall Width | - 2950 mm |
| Weight in air | - 10 tons |
| Weight in water | - 8.5 tons |
| Depth of operation | - 500 m |
| Operational speed | - 0.5 m/s |
| Max speed | - 0.75 m/s |
| Max climbing angle | - $8.5^{\circ}$ |
| Slurry Flow rate | - 45 $m^3/h$ |
| Concentration (max.) | - 30 % |
| Mining Output (max.) | - 12 t/h |
| Particle Size (max.) | - 8 mm |
| **Flexible Riser System** | |
| Hose size | - 75 mm |
| Hose Spool length | - 100 m |
| Hose- cable attachment | - at 6m intervals |
| Hose Handling System | - Winch rated at 500 kgs and max. peripheral speed of 0.5 m/s |
| **Power Supply, Control and Instrumentation System** | |
| Cable | - Electromechanical multiconductor cable.<br>- Breaking strength :400 kN |
| Power supply | - 120 kW Power transmitted at 3000 V through multicore conductors |
| Signal Transmission | - Signal transmitted thro' 2 optical lines on TCP/IP |
| Data Acquisition System | - PC based field bus system |
| Transducers | - Velocity, heading, pitch, roll, vision etc. |
| Winch for handling Cable | - 1.6 m dia.x 1.4 m length; Speed : 0.5 m/s |

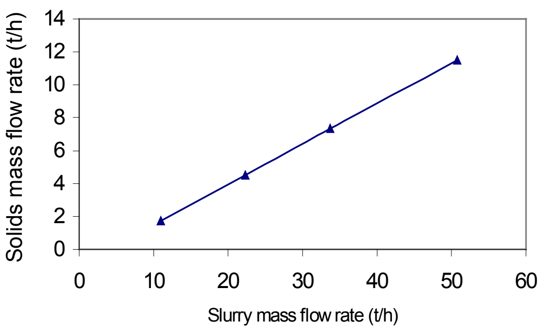
Fig. 3 Underwater Mining System : Technical Details



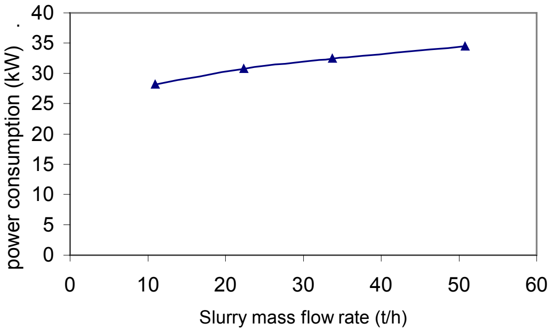

a. Set flow rates and slurry flow rates of positive displacement pump




b. Density of slurry pumped by positive displacement pump




c. Solids mass flow rate obtained during pumping tests




d. Power consumption of positive displacement pump during tests

Fig. 4 Performance tests on pumping system during third test (410 metres depth)

The third test was done off Tuticorin coast at 410 metres water depth. The underwater mining machine was launched to reach the ocean floor. The required S shaped profile was obtained at the bottom by spooling out an extra umbilical length of 80 metres. The sea bed soil was silty clay. After carrying out system health checks, the cutter and the slurry pump was started. Pumping operations were carried out in the volume flow range of 10-45 $m^3$/h. As the pumping system had a positive displacement pump, measurements of volume flow rate was done using stroke rates measured and by batch mode measurement techniques. The maximum density of slurry pumped measured by nucleonic density meter was 1170 kg/$m^3$ and the average density was 1135 kg/$m^3$. The maximum concentration of slurry pumped was 22%. Figure 4 shows the details of performance of the pumping system. The set flow rates can be very closely achieved with the help of positive displacement pump which has high volumetric efficiency. The pumping tests were carried out for a duration of 40 minutes.

The pumping of sea floor material by a positive displacement pump mounted on the mining machine has confirmed that this pump can be effectively used for ocean mining applications. Normally the positive displacement pump has been used in the past only for land based applications.

The sea floor where tests were carried out had soil of very low bearing strength. The underwater crawler vehicle had experienced a sinkage of about 750 mm. Maneuverability tests on the system could not be carried out due to this high rate of sinkage. Verification of mobility of the mining vehicle with closed loop controls for slip and speed is vital for mining operations. So it was decided to carry out the maneuverability tests on the mining machine at lower depths where sea floor had sandy material and higher bearing strength.

The fourth test on the underwater mining system was carried at 33 metres depth off Tuticorin coast where sea floor material was sand with adequate bearing strength. Launching operations were carried following the similar methods adopted for the third test.

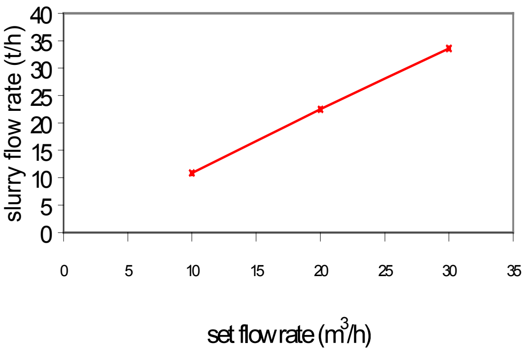
After carrying out system health checks, the cutter and the slurry pump was started. Pumping operations were carried out in the flow rate range of 10-30 $m^3$/h. The maximum density of slurry pumped was 1150 kg/$m^3$ and the average density was 1.13 kg/$m^3$. The maximum concentration of slurry pumped has been 18.5% by weight. Figure 5 shows the details of performance of the pumping system.

Maneuverability tests were carried on the underwater mining system under open and closed loop control. Under open loop control the mining vehicle was operated under independent joy stick control for left and right drives. Under closed loop control, the vehicle was set to move at a particular speed and heading. The vehicle followed the set point as shown in figures 7 and 8. Figure 7 shows the left belt speed and the right belt speed obtained over a period of time. Figure 8 shows the set heading and the actual heading over a period of time. It can be seen that the heading follows the set value more or less smoothly. In order to avoid slippage of the track belts and consequent sinkage of the vehicle, an automatic slip control is also incorporated. This was also verified during the course of the tests.

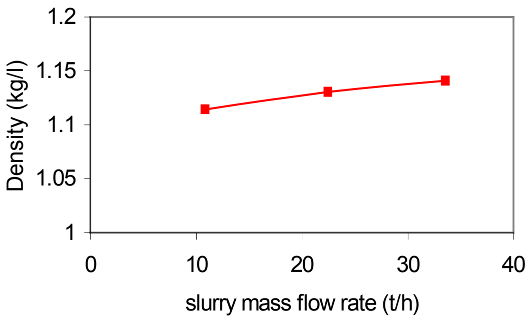
## FUTURE ENHANCEMENTS FOR THE FLEXIBLE RISER SYSTEM

Based on the experience gained from the tests flexible riser systems to be developed in the future will have the following enhancements.

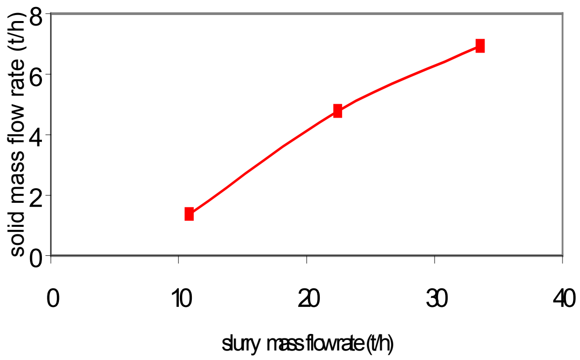
Launching and retrieval operations of the underwater mining system will be performed from ships/ vessels equipped with a launch platform and dynamic positioning system. The flexible riser will be designed to take the entire weight of the mining machine for recovery operations in the event of failure of the electromechanical cable. Materials like aramid fibres will be used in construction of hose and armour of cable to take care of high tension due to increase in depth. Design and development of components for subsystems will be based on materials having high strength per unit weight as well as adequate corrosion



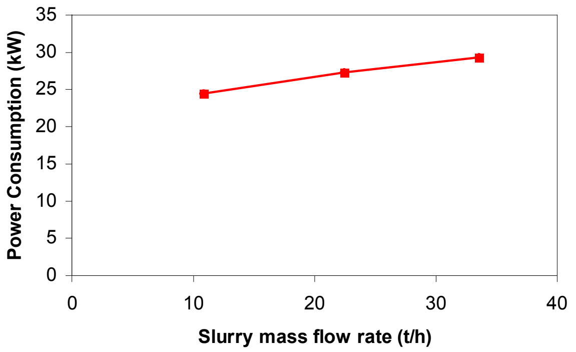

a. Set flow rates and slurry flow rates of positive displacement pump




b. Density of slurry pumped by positive displacement pump




c. Solids mass flow rate obtained during pumping tests




d. Power consumption of positive displacement pump during tests

Fig. 5 Performance tests on pumping system (33 metres depth)

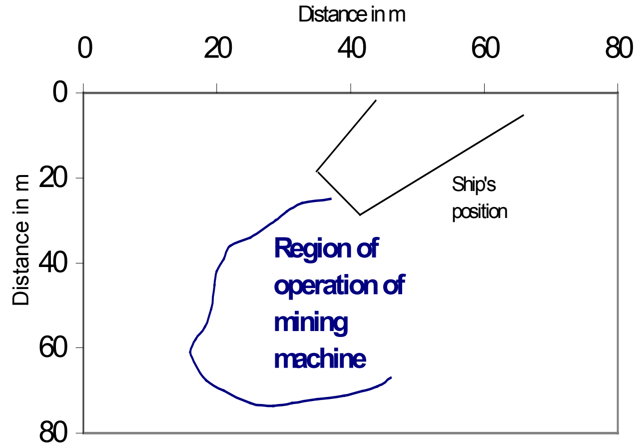



Fig. 6 Region of operation of underwater mining machine during tests

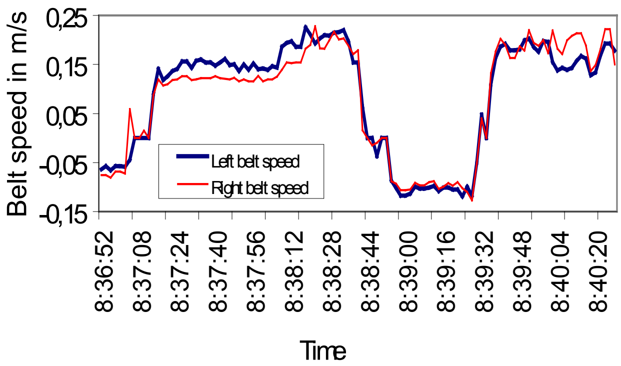



Fig. 7 Speed of left and right belt drive during operations

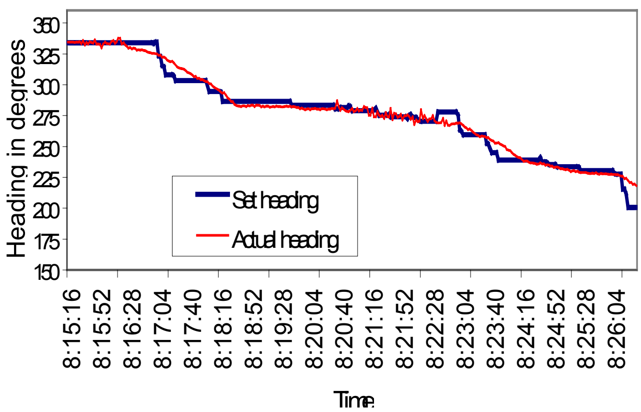



Fig. 8 Set Heading

resistance properties. This will enable reduction in overall weight as all the electronic systems will be enclosed in vessels to withstand high pressure of 600 bar. The riser will be designed taking into account parameters which can be broadly classified as: loading caused due to slurry flow, self weight, currents in the ocean, buoyancy packages, mobility of the mining vehicle and elastic properties of the riser. A mathematical model developed using finite element methods (Grebe, 1997) will be used for designing the riser.

In the second phase the manipulator arm of the underwater mining vehicle will be replaced with a collector having nodule pick up and sieving devices. A crusher will be mounted on the mining vehicle which will crush the nodules to adequate size suitable for trouble free pumping operations. The system is proposed to be realised and qualified at depths less than 500 metres by laying artificial nodules on the ocean floor.

Based on the performance of the collection and crushing systems, it is proposed to develop the integrated mining system for mining nodules and qualifying in the Central Indian Ocean Basin

## CONCLUSION

The underwater mining system having a mining vehicle with a single stage positive displacement pump and a flexible riser system has been successfully realised and qualified in shallow waters. Pumping of sea floor material has been achieved from 410 metres depth and maneuverability tests have also been successfully carried out. Such a system is a novel one tried out after the Law of the Sea treaty came into effect. This system is very likely to provide a cost effective and reliable solution for deep sea mining of manganese nodules. However a lot of investigations have to be done before this concept can be successfully qualified for such applications.

## REFERENCES


Atmanand, MA, Shajahan,MA, Deepak CR, Jeyamani, R, Ravindran, M, Schulte, E, Panthel, J, Grebe, H and Schwarz, W (2000). Instrumentation for underwater crawler for mining in shallow waters, *Proc. International symposium of Autonomous Robots and Agents,* Singapore, May 26, 2000

Brink, AW and Chung JS (1981). "Automatic Position Control of 300000 tons ship during ocean mining operations" *Proc. Offshore Tech. Conf*. Houston, Texas, OTC 4081, pp. 205-224.

Chung JS, Whitney AK and Loden WA (1980). "Non linear transient motion of deep ocean mining pipe", *Proc. Offshore Tech. Conf,* Houston, Texas, OTC 3832 pp. 341-352.

Chung, JS and Tsurusaki, K (1994). "Advances in Deep-Ocean Mining Research", *Proc. 4th Int. Offshore and Polar Eng. Conf.,* Vol.1, ISOPE, Osaka pp. 18-31.

Chung, JS and Olagnon, M (1996). "New Research Directions in Deep-Ocean Technology Developments for Underwater Vehicles and Resources", *Int J Offshore and Polar Eng*, ISOPE Vol.6 No.4, pp.241-243.

Chung, JS (1996). "Deep Ocean Mining: Technologies for Manganese Nodules and Crusts", *Int J Offshore and Polar Eng*, ISOPE Vol. 6 No. 4, pp. 244-254.

Deepak, CR, Pugazhaandi, M, Paul, S, Shajahan, MA, Janakiraman, G, Atmanand, MA, Annamalai, K, Jeyamani, R, Ravindran, M, Schulte, E, Panthel, J, Grebe, H, Schwarz, W (1999). Underwater sand mining for shallow waters, *Proc. 3rd Ocean Mining Symposium of Int. Soc. of Offshore and Polar Engineers*, Goa, November 8-10, 1999

Grebe, H (1997). "General Mathematical Model for the Hose Connections between the Mobile Deep Sea Devices and their Mother Stations". Ph.D. Thesis, IKS, University of Siegen, Germany.

Handschuh, R, Grebe, H, Panthel, J, Schulte, E, Wenzlawski, B, Schwarz, W, Atmanand, MA, Jeyamani, R, Shajahan, MA, Deepak CR, Ravindran, M (2001). Innovative Deep Ocean Mining Concept based on Flexible riser and Self Propelled Mining Machines, *Proc. 4th Ocean Mining Symposium of Int. Soc. of Offshore and Polar Engineers*, Szczecin, Poland, September 23-27, 2001

Heine, OR and Suh, SL (1978)0. "An experimental nodule collection vehicle design and testing", *Proc. Offshore Tech. Conf,* Houston, Texas, OTC 3138, pp. 741-749.

Kuntz, G (1979). The Technical Advantages of Submersible Motor Pumps in Deep Sea Technology and the Delivery of Manganese Nodules, *Proc. Offshore Tech. Conf.*, Houston, Texas, OTC 3367, pp 85-93

Ravindran, M, Schwarz, W, Jeyamani, R and Grebe, H (1999). Shallow-water Sand Mining Operation, *Proc. Offshore Tech. Conf.*, Houston, Texas, OTC 10730.

Rehorn, I (1994). "Development of a Deep-sea Full-track Vehicle (Caterpillar vehicle) and Testing its Internal Tractional Resistance". Ph.D. Thesis, IKS, University of Siegen, Germany.