CHAPTER - 5

DEEP SEABED MINING
The deep seabed mining with special reference to developmental status and requirements is presented in this chapter. During last three decades many patents for various components of mining systems have already been issued. The exploration work done so far reveals that although the task is far from being completed, the possibility of commercial mining using first generation equipment and methods is foreseen in near future.

5.1 TYPES OF AVAILABLE MINING SYSTEMS

Nodule mining technology involves picking-up of the nodules from the ocean bed and bringing them to the vessel. Following four alternative design concepts for mining systems have been developed and are being improved further.

- Passive nodule collector with hydraulic lift or air lift system (Fig. 5.1)
- Self propelled active collector with hydraulic lift or air lift system (Fig. 5.2)
- Continuous Line Bucket (CLB) Mining systems (Fig. 5.3)
- Modular or shuttle Mining system (Fig. 5.4)

All the systems have been developed and tested over the years. Broad features of each mining system are outlined in the following paragraphs to provide an overall picture.
Figure 5.1 The passive towed system

Figure 5.2 The active self-propelled system

Figure 5.3 The continuous line bucket system

Figure 5.4 The submarine shuttle system
5.1.1 Hydraulic mining system (pump lift/ air lift)

A lift pipe, fitted to the ship, extends close to the bottom of the seabed. A collector mechanism is linked to the end of the lift pipe and it picks up the nodules and feeds them into the pipe. The nodules are then either pumped up through the pipe by pumps fixed to the pipe, or sucked up through the pipe by compressed air injected into the pipe. Two types of hydraulic mining systems are given in Fig 5.1 and 5.2.

In 1978, Ocean Management Inc’s (OMI’S), international team conducted a pilot mining test (PMT) in the eastern equatorial Pacific (Middelhaufe, 1979; Bath, 1989; Oebius, 1993). The international Nickel Co. (INCO) was one of the OMI’s partners. The experts from Germany and Japan also participated in this endeavor. The basic elements of the mining system can be divided into following subsystems.

a. Collection sub-system (Passive or Active collector)

b. Lift sub-system

c. Mining ship sub-system

5.1.2 Continuous Line Bucket (CLB) mining system

A long continuous loop of rope, attached with draft buckets, is hung over a surface platform in sea such that end of loop touches the sea floor. When the loop is caused to rotate, the buckets during their passage on sea floor, excavate
nodules and carry them to the surface. If the platform moves in a direction of
right angles to the plane of the loop, then a path having its width equal to the
length of the platform is swept across the ocean floor. This principle of
Continuous Line Bucket System (CLB) is represented in Figure 5.2. Japan
Ocean Resources Association used their vessel chiyoda Maru No.2 for
successful testing of CLB Mining system during 1970 (Masuda et al., 1971). The
components of the system consisted of bucket sub-system, rope sub-system and
ship sub-system. The end of the main cable is brought from storage in the hold,
through the bow friction drive, by passing the outboard idler pulley, over the idler
pulleys on the superstructure and through the stern drive in normal fashion. It is
then manhandled outboard of the ship to the bow friction drive, where it is
secured above the idler pulley. The line is opened out so that the loop falls
freely. To compensate for the buoyancy of the rope, weights are added to the
bucket loops until line equivalent to about 1.5 times the depth of water is opened
out. This is followed by attachment of buckets at regular interval of around 25 M
until a total length of line equal to three times the water depth has been let out.
The line from the hold is then cut and the two ends are joined to form a
continuous loop. As the loop is rotated through the system, weights and buckets
are removed at the forward drive; the buckets are emptied and then handled to
the stern and placed in the line. The improved version of the system was also
tested in 1987, using coastal fishing vessel up to a depth of 50 m (Masuda and
Cruickshank, 1994).
5.1.3 Modular mining system

The principle of modular mining system is outlined below.

The collector or shuttle unit is designed to have sufficient buoyancy so that it is weightless in water (Herrouin, 1999). The collector is launched with ballast material such that the weight in water of the ballast material is equal to the weight in water of the nodules to be collected. The thrusters propel the unit down steadily, against hydrodynamic resistance alone, till it touches the seabed. The collector moves on the seabed, and as the collection proceeds, ballast material is simultaneously ejected on the basis of an equal weight in water. Ballast material ejection is continued until the weight of the unit is zero or slightly negative. Finally, the vehicle is propelled by thrusters to the surface, docked with the surface ship, unloaded, serviced, and reballasted for a few mining cycle. Thus, very little onboard power is required to collect the nodules, the major source of energy being the potential energy of the ballast material. The modular mining system comprises two sub-systems viz., the collector unit and the surface platform. The scheme of the system is represented in Figure 5.4.

5.2 EFFORTS BY PIONEER INVESTORS

There are 7 pioneer investors under the Deep sea bed mining regime, only a few pioneer investors (now contractors) are active for research and development of deep sea bed mining technology. A brief summary of their efforts are given below.
France

In 1970 and 1972 - 1976, the French group, AFERNOD (the Association Francaise pour l'Etude et la Recherche des Nodules) conducted test of CLB system for mining Polymetalic Nodules. During the same period, other mining concepts were also scrutinized. In 1980, AFERNOD studied free shuttle mining concept which proposed the concepts of use of free unmanned submersible to collect nodules from sea bed and lift them to the surface. The program was then reoriented to a hydraulic lifting system with a motorized collector and was implemented in 1984 to 1989. A vehicle known as PLA2-6000 was designed, developed and performed a series of deep water dives in 1987 in the Mediterranean Sea demonstrating its capabilities of dynamic flight, landing and moving around at the sea bottom, and finally takeoff to the surface (Herrouin, 1999).

China

COMRA (Chinese Ocean mineral Resources R and D Association) has developed two types of collectors, a hydraulic collector and a hybrid collector, both on a caterpillar track, one with a mechanical and other with a water jet pick up using a Coanda nozzle (Liu, 1995; Liu, 1997; Liu and Ning, 1999). A flexible hose between the collector and a buffer system on the main pipe lift system is part of the total mining system. However no open sea tests have been carried out so far.
Japan

Japan intended to develop a prototype mining system based on the R and D activities before comprehensive Ocean test. In 1995 (Inokuma, 1995), the plan for comprehensive ocean test was reviewed and the plan for full test of the integrated system was changed to four experiments which would contribute to the overall development of the Deep Seabed mining system. After completion of R and D project on nodule mining system, a tow sledge-type collector with a pressurized water jet flow collecting mechanism based on the Coanda effect was designed. The larger nodules are crushed in the collector before lifting. The collector will be towed by a pipe string composed of a flexible hose and lift pipes, collect nodules with water jet, separate seafloor sediments, crush nodules to a desirable size distribution, and feed them to the riser system. A large scale collector test was conducted in 1997 (Chung and Tsurusaki, 1994). The achievement in collecting efficiency was estimated as 87%. Japan does not have any plan right now and all R and D work towards mining technology development was stopped.

Korea

The Korean Ocean Research and Development institute (KORDI) started a 10 year program. As a part of the program nodule collector and integrated recovery system technology aspect was taken up. The work consisted of exploitation technology concept design, enhancement of existing sub systems which include a self propelled collector with flexible umbilical between the collector and the
buffer, enhanced buffer function and conventional lift systems. The test collector has been reported as developed however no ocean test has yet been carried out (Hong Sup, 1995).

India

As a part of joint activities with University of Seigen in Germany, a crawler based shallow bed mining system has been developed and tested up to 400 m as a part of developing deep seabed mining system in phases. The system consisted of crawler based collector module, riser module (flexible hose) and control module (Fig 5.5)

The development of nodule collector and crusher along with the flexible hose riser system for a shallow depth is under progress. The data generated from testing at shallow bed has been used for a preliminary design documents for nodule mining up to a depth of 6000 m.

Germany

Fig. 5.5 Under water crawler undergoing land tests

5.3 REVIEW OF THE EXISTING SYSTEMS

5.3.1 General

The general assembly of the UN adopted a declaration principle as a come out of negotiations that took place in the seabed sub-committee. The declaration (General Assembly resolution 2749 (xxv)) was "the seabed and ocean floor, and
the subsoil thereof, beyond the limits of national jurisdiction as well as resources of the area, are common heritage of mankind”. It was also declared that this area” shall be open to use exclusively for peaceful purposes by all states without discrimination “.

In January 1974, private companies in the United kingdom, United states, Canada, Japan, Belgium, Italy and Germany were forming industrial consortia with the expressed purpose of exploring for and mining deposits of these minerals. The Kennecott Consortium (KCON) was formed in January 1974 and included Kennecott corporation parent company being Sohio of the US, Rio Tinto Zinc Corporation of the United Kingdom, British Petroleum Company Ltd. of the United Kingdom, Noranda Mines Ltd. of Canada and the Mitsubishi Group of Japan. In may 1974, Ocean Mining Associates (OMA) was formed as a partnership registered in the United States, with the US steel corporation of the US, Union Miniere of Belgium, Sun Company of the US and Ente Nazionale Idrocorburi of Italy as partners. AFERNOD was also established in 1974 in France and consisted of France's Centre National pour L'Exploitation des Oceans (CNEXO), the Commissariat a l' Energie Atomique, Societe Metallurgique le Nickel and Chantiers de France-Dunkerque. In March 74, Deep Ocean Resources Development (DORD) was formed as a public corporation in Japan. In February 1975 OMI was incorporated in the US with participation of INCO Ltd. Preussage AG of Germany SEDCO, Inc of the US and Deep Ocean
Mining company Ltd. of Japan. The Ocean mineral company (OMCO), consortia formed in November 1977 with Lockheed systems Co. etc.

The development of hydraulic pump lift and hydraulic air lift systems is based on the technology and experience gained in operating oil risers in deep waters and the know-how built in connection with slurry transportation of minerals at sea and on land (Amann, 1994).

The high reliability and survivability associated with various types of collectors designed and developed and tested by various agencies for the last three decades mainly concentrated on collectors which can be divided into passive and active collectors. The passive concept and ability to function without power, qualify them for use as commercial scale collectors. Passive collector is not acceptable for consideration of commercial mining system due to very low nodule collection and sediment rejection efficiency. According to Mr. Brockett CEO, sound oceanic system, USA (former OMI sr. engineer), the passive rake has the highest potential, however it needs further R and D investigation (Brockett and Kollwentz, 1977). The passive plow concept should not also be considered due to excessive seafloor interactions.

5.3.2 Hydraulic mining system

The mechanical concept of US consortia has very high collection efficiency but it needs separate hydraulic sediment separating sub-systems. The concept has a large number of moving parts and is most complicated. The mechanical ramp
design is more complicated than the drum design, but its ability to eliminate sediments is higher. The survivability and reliability of the system for long operation is doubtful (Brockett, 1999).

The family of hydraulic collectors has the potential for commercial mining operation. There is no substantial difference between design of hydraulic or mechanical ramp collectors from the point of view of collector size, weight, power and handling requirements (Brockett et al., 1979). The two considerations that would significantly influence the decision to use either design are system reliability and maintainability. According to recently published literature on the topic, hydraulic pump/air lift system appear to be the most promising. As per Kaufman, continuous hydraulic dredging approach (using air lift pumps) has been found the most effective system for efficient first generation commercial mining. Compared to CLB system, hydraulic mining system offers far more flexibility for control of the collector sub-system (self-towed collector) and the system can be designed as sufficiently rugged to surmount obstacles of a size, which is readily detected by a previous survey. In view of the relative merits of this system over other mining systems, most of the developmental and experimental works done so far relate to hydraulic mining system only. However, hydraulic mining system has the following limitations.

- It involves bulky and complicated sub-system, which are difficult of handle during operation at sea. A lot of auxiliary handling and controlling
equipment are required in addition to the pipe, pump lift/air lift and the equipment for crushing at seabed.

- Other difficulty with hydraulic mining system is its high reliability requirement. A minimum of 45 - 90 days mean-time-between-failure (MTBF) is considered essential. Further works on design of the propulsion mechanism in a self-propelled collector to achieve smooth movement on the sediment, positioning of the mining ship, the lift pipe and the collector; and the technology of slurry transfer are necessary, before a large-scale system test could be conducted to establish the minimum MTBF defined above.

The relative advantages and disadvantages of Air Lift (AL) and Hydraulic Pump Lift (HP) approaches are given below.

- The capital cost is almost the same for both the designs (AL and HP), while the energy cost is higher for AL, maintenance cost is higher for HP (Herrouin et al., 1989).
- Both the designs are equally reliable (i.e., meantime-between-failure is equal).
- The AL sub-system is likely to present significantly greater handling problems since it is essentially a two-pipe sub-system.

The decision between the two approaches is not readily apparent, therefore, some consortia were planning test of both lift approaches in their large scale
demonstrations to choose the final one. But due to uncertainty, the large scale
demonstrations did not take place.

5.3.3 CLB mining system

Some of the merits of CLB system are-

- The dredging technology and the operation of the system is simple
- There is high degree of flexibility in working in following respects
- Deposits with any size of nodules can be handled
- Big changes in bottom topography is permitted
- Bottom sediments of varying characteristics in greatly varying water
depths can be handled
- System being light weight, can be mounted on any ocean going vessel
- The sediments are washed out during ascent of buckets, hence no
separation problems on the surface
- Installation of underwater components is simple and rapid
- The submerged components - fibre rope and buckets, are available for
routine checks and maintenance once during each cycle
- The system is potentially energy efficient because the descending line is
counter-balanced by the ascending line and no water quantity is required
to be transported with the nodules. As per Masuda, CLB system requires,
7,200 HP for a production of 6,000 tonnes per day while a comparable
hydraulic dredging system requires 15,000 HP
• The system potentially involves relatively less capital cost compared to hydraulic mining system. As per Masuda, capital expenditure for hydraulic system is as much as several thousand per cent higher compared to CLB (system)

• The operating cost is low (As per Masuda, hydraulic mining system has as much as 50% higher operating cost compared to CLB system)

• Scaling up of the system is easily possible (5 tonnes capacity buckets using 25 tonnes breaking strength cable can produce 5000 tonnes per day at moderate costs)

The limitations of the system are -

• The ascending and descending segments of the line are prone to tangling, which may result-in immediate close-down of operation

• As the segment progress perpendicular to its line of action, the bottom line segment is highly vulnerable to snagging

• The efficiency of nodule pick-up is low (Loose sediments like sand silt and clay tend to fill-up the buckets, which not only affect the efficiency but also lead to serious environmental problems)

• Difficulty in precise tracking lead to insufficient collection from seabed

• There is lack of control of individual buckets (buckets may stay on the bottom long after they are filled and thus unnecessarily obstruct uncollected nodules, or they may be withdrawn before being completely filled)
In view of the above limitations, this system is being looked at in a limited way i.e., only of five consortia.

5.3.4 System Developed/ being developed by Pioneer Investors

COMRAS attempt for developing a mining system is basically for environmental friendly mining system. The design consideration has been taken into consideration of pick up system and transport of clean nodules without sediment. They have further considered, the weight of the collector to minimize the sinking into soft sediment, pipe size to prevent jamming and waste water discharge at a depth least likely to create negative impacts. Other design criteria were optimum collector width and high pick up efficiency.

AFERNOD's study of free shuttle mining concept for nodule mining could not progress much due to its economics for several decades.

JAPAN, though deep sea mining test carried out on the top of a Sea mount in the central-north-western Pacific Ocean, the collection efficiency was 87% with a collector speed between 0.3 and 0.8 knots.

To decrease the down time of the collector the total reliability of the system is the most important. In addition appropriate avoidance methods from stormy weather needs to be developed from the hardware and software point of view to increase overall efficiency, buffer like underwater subsystem perhaps would be appropriate between collector and lift system.
INDIA's mining technology development program is based on crawler based collector with a flexible hose riser facility. Indian systems would be having a large number of moving parts, sensors which may be a bottleneck considering mean time between failures which is most important factor of the success. The Seabed current change due to sub marine storm and suspended sediment floors can cause unexpected difficulties. The absence of catenary may create problem in the event of ship movement. There is need to make a catenary and the two speeds must be synchronized and the tensions are limited by the catenary which must somehow be controlled either by ship or by the crawler. The best possible way to solve the problem perhaps is to provide a buffer system between the collector and riser system.

5.4 Requirements of an environmental friendly mining system

It is suggested that on the basis of extensive analyses of the existing systems that the following basic issues need to be considered for designing and developing environmental friendly deep sea bed mining system (Thiel and Forschungsverbund, 1995; Oebius, 1997).

Sediment

It is important to remember that the collector is only one component in the mining system. While it is certainly an important and critical component, it is only one of many and as such it must be compatible with the rest of the components in the system. As a simple example, a collector with a nodule throughout capacity of 100 tonnes per hour will potentially clog and cause to fail a riser system capable
of lifting only 80 tonnes per hour. Similarly, the collector must be matched to the forward speed and available power of mining system, and must be compatible with the command and control system that interfaces with the collector.

The top layer sediment will be completely removed by the collector and some of the sediment will be transmitted together with nodules to the mother vessel. The collecting system should be designed and developed such that it should clean the soil from the nodule near the collection point and leave the soil at the seabed. CLB kind of miner may not meet these criteria. A properly designed system may be required to meet these criteria.

**Sediment plume**

The sediment plume likely to be created by the mining operation is regarded to be responsible for damage to the benthic organism (both flora and fauna). The initial height of the plume generated by a collector will be the decisive factor for spatial dispersion of plume. The heavier one would be settling early near the immediate operation site and lighter sediment plume will disperse according to the currents at the sea bottom. This is a normal phenomenon for sediment plume. It is necessary to minimize the height of the plume for limiting the range of sediment plume.

**Mining contour/track**

From engineering point of view, the collector movement on the seabed is likely to be regular in order to optimize the efficiency of the system. The paths of mining
system should be perpendicular to the direction of the water current so that the re-suspended bottom sediment can only disperse and resettle in the already mined area and it would avoid burying the nodule area. In this process, sediment re-sedimentation can be contained in the disturbed area by the nodule collector leaving very little quantity of re-suspended soil resetting in the areas beyond mined site. A towed collector will lead to random track on the sea floor causing more environmental hazard. The need for self-propelled collector with an insitu central system would be having comparatively less environmental impact.

**Weight of the collector**

This is most important criteria to contain the environmental impact. The weight of the collecting system should be as light as possible. It has been reported that Archimedean screw principle self-propelled mining system had tendency to dig the sediment in case of hard obstacle in the front, the caterpillar principle collector may overcome the obstacle if a proper design consideration is given at the initial stage.

**Riser system jamming**

The riser system jamming may occur due to various reasons. It is necessary to keep a release valve at the pump itself which can be opened in case of jam. The leakage of pipe may create environmental effect on the water column. Appropriate pump with mechanism of release valve should be kept for this purpose.
Discharge of waste water

Mother vessel should have proper storage facility for nodules. The waste water discharge has to be made below the oxygen minimization zone to avoid problem on the sea surface water.

Control system

In order to have good maneuverability of nodule collector, self-propelled vehicle would be the best option taking into consideration of the passive as well as CLB type of collector. Microprocessor based controlled mining / collection system would be preferred option for high recovery rate of the nodule resources.

Reliability

The collector should also be compatible to the environment in which it must operate i.e., high hydrostatic pressure at 5000 / 6000 m depth, sea floor topography, soil bearing strength of seabed sediments and nodule distribution.

As the collector would be at a depth of about 5000/6000 m, it must be reliable and capable of operating for longer duration. Another aspect is equally important that sediments need to be eliminated substantially before sending the nodules to the riser system to avoid likely environmental impact due to discharge back the sediment at a permissible depth of water column.
Redundancy

Redundancy is another key characteristic of the ideal collector. It is important that all critical collector components have redundant or back-up components. It is inevitable that components within the mining system will fail and it is therefore desirable to have redundancy wherever possible. Because it is impractical to have 100% redundant systems, the collector should be designed in such a way that failure of one non-redundant component does not significantly interfere with the primary function of collecting nodules. This idea strongly points towards the concept of modular collector design. The increased complexity associated with modularity is likely overshadowed by the increased flexibility and redundancy provided by modular designs.

5.5 The emerging concept proposed

➢ During the last three decades, there were several achievements. Electronic advances such as instrumentation, monitoring, data transfer, control capabilities and positioning had greatly improved and reduced the costs. Two issues that require immediate attention are collector and submersible pumps for extensive studies.

➢ The remoteness of the collecting modules needs to be reliable in the long term and should be as simple as possible.

➢ There should be minimum moving parts. Mechanically, the collecting system should be simple, rugged, flexible and very light.
Redundancy of the subsystem is also important so that a component failure should not affect the total system.

For a commercial system, collector width is critical factor and is a function of nodule coverage, ship speed, collector efficiency and anticipated operating time. A lot of improvement has been made in the pumping system and submersible pump would be superior for use in the riser system.

The extensive analysis of the available design concepts and various developments over the years, the author has formed the basis for the emerging concepts. The **emerging concept** (Fig. 5.6) consists of a simple self propelled collector system, flexible hose connection between buffer systems and riser pipe (hydraulic lifting) with mother vessel. The various parameters relating to different activities are summarized in table 5.1 for design, development of mining system.
Fig. 5.6: Conceptual model of mining system
Table 5.1: Parameters required for design and development of mining system

<table>
<thead>
<tr>
<th>Activities</th>
<th>Parameters/sub-systems</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| Exploitation | • Topography  
• Soil characteristics  
• Nodule abundance  
• Meteorological conditions | Comprehensive data must be collected in advance |
| Exploitation miner | • Miner specific functions (locomotion, collector, crusher)  
• Miner positioning | |
| Lifting | • Flexible hose  
• Pipe  
• Pumps | Extensive R and D work on the Collector and hydraulic pumps has to be carried out. |
| Surface support | • Handling system (nominal and emergency conditions)  
• Storage  
• Ore transfer at sea | |
| General positioning of the system | • Knowledge of environmental ecosystem : baseline studies  
• Water column ecosystem : baseline studies  
• Consequence of plume of sediment on deep sea ecosystem  
• Consequence of discharged water on water column ecosystem | Comprehensive study must be carried out well in advance |

However author suggests the following critical issues of mining operation which should be kept in mind.
**Marine transport**

Since the capital investment in the mining component is considerably high, it is not desirable to merge the mining and transportation functions in one vessel. It is economically better to continuously use the mining vessel for maximum possible time (about 300 days per year) for optimum utilization and to use bulk carrier for transport of nodules from mining vessel to shore terminal. The nodules are proposed to be carried from the mine site to the port-based processing plant with the help of two transport vessels.

In order to maintain the production, the vessel should be capable to operate in high sea state and at an arbitrary heading with reference to the weather. The transfer system should be able to operate in high sea state and transfer of nodules needs to be affected at relatively low speed of 2 to 4 knots in a situation where sea states may be changing and the maneuverability of the mining vessel has to be carried out strictly as per predefined planning. The transfer system would be used for transportation of consumables, crews and spares from the shore terminal to mining vessel and brings back unused to shore. The nodules may be transferred in the following way.

a) Slurry transfer

b) Pneumatic or conveyor transfer

There are various advantages, disadvantages in both the modes with respect to stability, relative positioning of the mother-ship and transport ship system during
mining operations, connection of transport system with mother ship, etc. The selection and development of transfer at sea concept involves many interdependence decisions. There, it has to be addressed by system engineering approach, which includes development of designs, technical requirements and cost implication of various approaches. The position keeping may be difficult even in moderate sea states. The nodules transfer in large volumes without considering the operation of the mining system poses a major problem and requires further experimentation, which is yet to be attempted by any country/consortia. However, for the cost estimate purpose, only slurry transportation system is considered.

**Shore terminal**

The broad functions of the shore terminal would be unloading, storing, transporting of nodule slurry to processing plant, logistic support to the mining operations in terms of supply of crew personnel, technicians, consumables, spares, receipt of unused materials, communication, etc.

**Size of the vessel**

In order to have 1.5 million tonnes of dry nodules, we have to mine 2.24 million tonnes of wet nodules, which need to be transported to the shore terminal in 300 working days for processing. The size of the vessel has to be based on the following factors.

- Annual quantum of nodules to be transported;
- Availability of draught in Indian port.
The bigger size vessel for transportation would be advantageous for minimizing the capital cost and operating cost. The limiting size of the vessel is determined by the landing limitations of the ports. The mining vessel (mother ship) size needs to be taken into consideration for limiting the size of the vessel. The precaution has also to be taken to ensure continuous operation of the transport vessel to achieve the target. It is assumed to use 75,000 DWT vessels for transportation. The necessary pumping system for transportation of the slurry can be located either on the vessel or on the shore depending on the suitability of working. In case of tankers, pumps are located in the vessel only.

Terminal sites

The approximate distances from the Central Indian Ocean mine site to various possible ports are as under.

- Paradeep: 3980 km.
- Madras: 3150 km.
- Goa: 3390 km.
- Cochin: 2680 km.

The preliminary survey indicates that the Paradeep or Cochin port would be able to meet the requirement. However, dredging would be required to maintain the draught and costing also has been made considering this aspect. Studies on hydraulic model and geo-technical investigations, etc. would be required for final selection.
**Number of transport vessel**

Assessing the DWT out of the vessel proposed to be used, the number of days required by a vessel for the full trip from Cochin can be calculated as below:

<table>
<thead>
<tr>
<th>Loading time</th>
<th>3 - 5 days</th>
</tr>
</thead>
</table>
| Travel time (to and fro) | \[
= \frac{3000 \times 2}{25 \times 24} = \frac{3000 \times 2}{600} = 10 \text{ days}
\] |

Therefore, one vessel can make about 19 trips and would transport about 1425000 tonnes. Total 2 vessels required to meet the target production. If any other port is chosen, the number of vessels required would be more.

Based on the preliminary analysis, either Cochin or Paradeep could be possible alternative choice. The detailed comprehensive investigation is required for selection. For the purpose of costing, Cochin has been taken as the shore terminal.