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High capacity offshore low-temperature thermal desalination plant: A new perspective

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ABSTRACT

National Institute of Ocean Technology (NIOT) has been working on developing technologies to ameliorate the shortage of drinking water in island and other coastal areas. Towards this, various onshore desalination plants have been constructed and operated utilizing ocean thermal gradient. For high capacity ocean energy and desalination plant, going offshore is considered to be a viable option. This article discusses the experiences and work carried out for ocean thermal gradient based large capacity desalination plant. Offshore plants have their own complexities with regard to design of platform, moorings and sea water pipelines. These components were studied thoroughly and discussed in the article. The design philosophy and results have been presented for a design of 10 million liters per day (MLD) capacity desalination plant, mounted on semi-submersible platform moored in 1000 m water depth.

Keywords: Offshore thermal desalination plant, Semi-submersible, HDPE conduits, spread mooring, Kavaratti (Lakshadweep)

INTRODUCTION

Ocean is a vast source of energy and potable water, both of which need to be harnessed in a clean and green manner. Among different sources of energy from the ocean, ocean thermal gradient perhaps has the highest potential for both extraction of energy and fresh water since we are in the tropics. The process of extraction of potable water from the ocean has already reached its advanced state. Sea water desalination is attaining increasing attention of present day policy makers, especially with the growing demands that urbanization, population explosion, irregular rainfall and ground water contamination place on the fragile natural resources. Membrane and thermal desalination processes are both popular today.

Low temperature thermal desalination (LTTD) is one process that uses the availability of a temperature gradient between two water bodies or flows to evaporate the warm water at low pressure and condense the resultant vapour with cold water to obtain fresh water. The temperature difference that exists between the warm surface sea water (28^0~30^0 C) and deep sea cold water (7^0~15^0 C) could be effectively utilized to produce potable water and generate power (Rognoni et al., 2008). The advantage of using this method is that steam is not required.

National Institute of Ocean Technology (NIOT) under the Ministry of Earth Sciences (Government of India), strives to develop reliable indigenous technology to solve the various engineering problems associated with the harvesting of living and non-living resources in the Indian Exclusive Economic Zone (EEZ), which is about two-thirds of the land area of India. The LTTD process as mentioned above, which converts sea water into potable water using natural ocean thermal gradient, has been successfully demonstrated by NIOT at Kavaratti in Lakshadweep Islands for the first time ever in 2005 (Jalihal, 2022). Subsequently, this indigenized technology has been deployed in various islands of Lakshadweep recently.

This technology has transformed the lives of the islanders by improving their health. NIOT has also worked on offshore based desalination plants for augmenting the freshwater requirements of mainland. The offshore plants are considered gateway for large capacity ocean thermal gradient based energy and desalination plants. Design of offshore plant is challenging due to the complexities of various offshore components such as platform, moorings, large sea water conduits, integration and installation, etc. Nonlinear time domain dynamic analyses need to be carried out for offshore components which are constantly in a dynamic environmental with wave and currents (Vishwanath et al., 2020). The article discusses those challenges, works and studies carried out by NIOT for high capacity offshore LTTD plant. It also outlines design methodology and results for the proposed 10 MLD capacity Semi-submersible mounted LTTD plant at 1000 m water depth.

OFFSHORE LTTD PLANT

The main components of the LTTD plant are: (i) Heat exchanger like shell and tube condenser, (ii) Duct that transfers vapour from the flash chamber to the condenser, (iii) Sea water pumps to supply the warm and cold sea water, (iv) Vacuum system that maintains the flash chamber, vapour duct and the vapour side of the condenser at the design vacuum, at about 26.5 mbar (abs), and (v) Pipelines to draw cold water from the required depth.The pipeline is the most challenging part of the system. In an onshore plant, as in the case of islands, the deep water is very close to the shore. This is a special feature in the Lakshadweep group of islands. Thus the pipe has been designed to be in a novel configuration with one end in shallow waters near the shore and the other end, held by a weight in deep waters. The inverted catenary configuration is possible due to the inherent buoyancy of the material of the pipeline. For the mainland application of this technology, the drawing of the cold water is the challenge since the distance to the deep water is about 40-50 km from the east coast of India. This necessitates that the plant be located on a platform which is kept in position using moorings at a deep water location. The thermal process itself is invariant. To demonstrate that this technology can work offshore, a barge mounted desalination plant with capacity of 1 million liters per day (MLD) was taken up. It was successfully demonstrated by NIOT at 40 km off Chennai coast in deep water for mainland applications in 2007. The challenges included design, installation and maintenance of plant in deep water and transport of product water to the coast. For the first time in the world, a 1 m diameter and 750 m long HDPE pipe was towed, upended and connected to the bottom of a barge to pump deep sea cold water at around 10°C. The deepest single point mooring in Asia (i.e. 1000 m water depth) was designed in house and also fabricated indigenously for mooring the 1 MLD plant. This mooring performed very well and kept the barge moored during the demonstrations trials. The barge used for the 1 MLD plant had a central moon pool through which the 1 m diameter cold water pipe was suspended vertically to draw the cold water. The one MLD offshore LTTD plant as shown in **Figure 1,** successfully generated fresh water for several weeks.

The main outcomes of this plant are following.

(i) The short demonstration of the concept of producing fresh water on a barge moored offshore and generation of excellent quality of water.

(ii) Within a year, a long 1m diameter pipe could be assembled, towed and connected many times successfully albeit with some effort due to paucity of offshore handling equipment.

(iii) Successful single point mooring in 1000 m water depth

(iv) The experience gained and success in pipe deployment and installation, is an indication that pipelines for future larger plants can be handled by NIOT, and

(v) Offshore experience derived from the efforts at deploying, connection and operation can led to capacity building for future plants.

With the gained confidence it was felt prudent to design and install a unit for 10 MLD offshore plant.

SEMI-SUBMERSIBLE MOUNTED 10 MLD OFFSHORE PLANT

The requirement for offshore desalination is a stable all weather platform like semi-submersible floating platform to house the plant, a large cold water conduit/pipeline, and station keeping /mooring for the platform and an inter-connecting mechanism between conduit and platform to withstand the differential loads.Semi submersible floating platforms are utilized in various kinds of offshore structures because of their good motion characteristics. Minkenberg and Van Sluijs (1972) studied the motion optimization of semi submersibles. Vogt et al. (2002) studied about the stability of deep water drilling semi-submersibles. Halkyard et al. (2002) developed a deep draft semi-submersible with a retractable heave plate. The system combines the advantages of a semi-submersible with the operational motion advantages of a truss spar type floater.

In a semi-submersible, the primary buoyancy members are well below the water surface so as to be relatively unaffected by the action of surface waves. This causes a decoupling of its motion from the surface wave motion and consequently, it is significantly more stable than the conventional ship hulls.

A Semi-submersible platform was chosen for accommodating the desalination plant due to several reasons. Based on the size and weight of the plant equipments, the columns and pontoon of the semi-submersible can be of rectangular shape of suitable dimension, depending on the requirements of the plant operating conditions. The deck, column and pontoon are placed and configured according to requirement of process equipments. The minimum acceptable heave natural period for the semi-submersible is above 18 sec as it is far above the encountered swell period. For the given payload conditions, a four column semi-submersible platform with interconnected pontoons was chosen for the platform configuration.

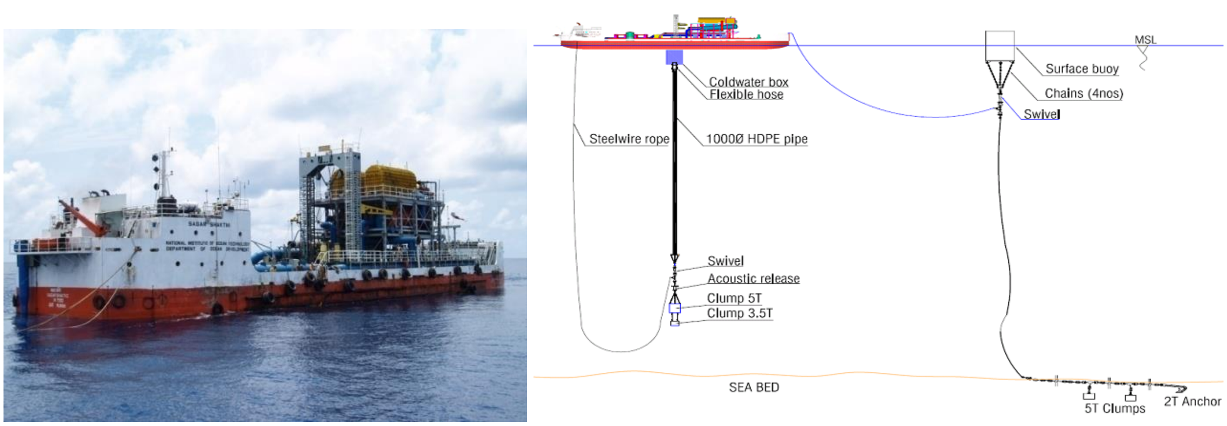

Figure 1. Barge mounted 1 MLD capacity Low temperature thermal desalination plant

The 10 MLD semi-submersible mounted plant platform, will have to be a larger displacement vessel due to the large quantities of water being handled by large plant equipment. For an all weather large platform, the design considerations are different. Several designs and analyses have been carried out with several configurations. The 10 MLD plant would have a 4 modules of 2.5 MLD units housed on this platform. Cold water supply pipelines necessarily have to be larger in size, requiring high attention in its design to suit its installation and integration with the platform. Being first of a kind in the world with no past references, several design challenges were to be addressed. Since the operational period of this offshore plant is proposed for 25 years, extremely harsh ocean environment were considered for the design. Various options and alternatives of design and the cascading effect of the changes on all discipline areas related to mechanical, pipelines, platform, moorings etc. was evaluated and final design was arrived at adopting the design spiral.

Semi-submersible hull

The platform hull is designed to support the main equipments along with the necessary utility systems in the main deck to generate 10 MLD fresh water. The sea water HDPE pipelines are connected to the deck at central position through conduit stiffening structure. **Figure 2** shows the platform with equipments on the deck. The hull consists of a square ring pontoon with four square columns at the corners. Four columns support the square truss type deck. The pontoons are subdivided into compartments for ballast water, diesel fuel oil, produced fresh water and pump rooms, and also taking into account damage stability requirements. An access tunnel runs through the pontoon providing access to various tanks and the pump rooms connecting the four columns. The pump rooms are subdivided with watertight bulkheads and doors in order to comply with damage stability requirement. The columns are subdivided by vertical and horizontal watertight bulkheads considering the damage stability requirements. The major analyses and studies that were carried out for the hull and topside design, include Platform Hull Sizing, Scantling calculations for Hull (Pontoon and Columns), Stability Analysis and Hydrodynamic Motion Analysis. Hydrostatic properties of the platform are shown Table 1.

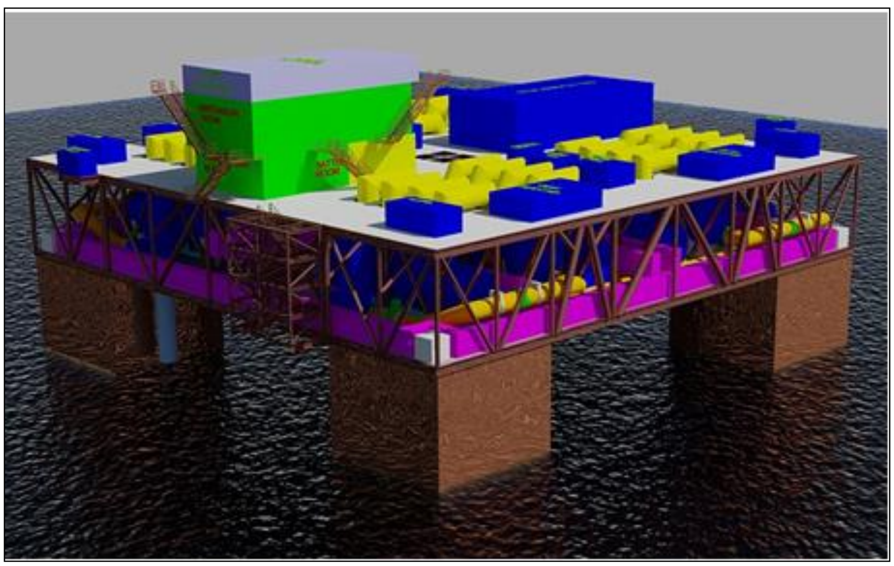

Figure 2. Arrangement of equipments on deck of the platform

Table 1. Properties of semi-submersible mounted LTTD plant

Parameter	Value
Draft (m)	18
Displacement of platform (t)	26000 (approx.)
Square ring Pontoon (m)	60x13.4x7
Column (m)	13.4x13.4x21
Position of COG from keel KG (m)	16.2
Metacentric height, GM (m)	5

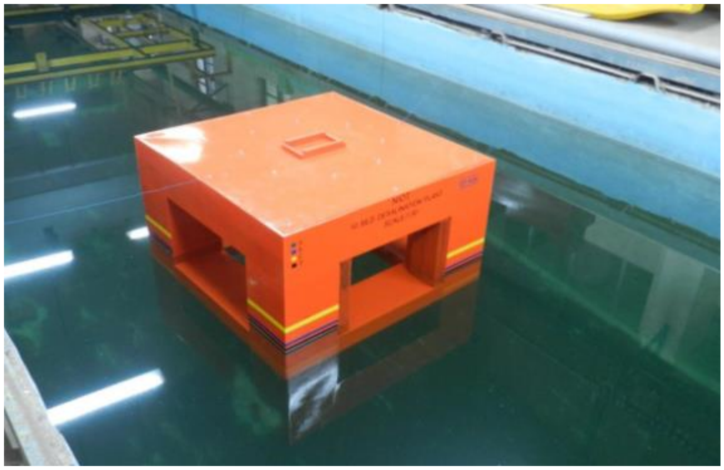

Figure 3. Physical model testing in wave flume

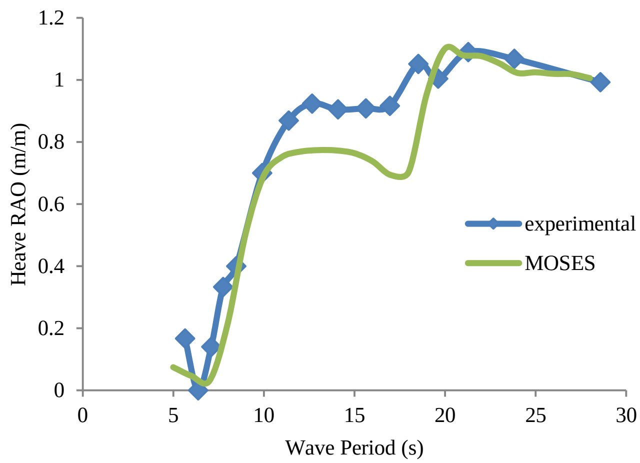

Figure 4. Comparison of RAOs with wave period

The stability of the floating platform was checked in accordance to IMO MODU (2009). The complexity of the motion response of offshore floating platform requires advanced simulation tools for the accurate assessment of the sea keeping behavior. Commercial software tools was used which is based on potential/diffraction theory for force estimation. The sizing of the water plane area, which plays a crucial role in the motion response of a floating body was done iteratively for a good response characteristic of the platform.

A 1:50 scale model of semi-submersible was prepared and tested by Ocean Engineering Department at IIT-Madras. Model tests were carried out for two conditions, free floating condition and moored condition, free floating further divided into free floating response case without considering conduit bundle, and free floating response case with central conduit bundle. Figure 3 shows the model being tested in IIT-Madras wave flume.

A comparison of heave Response Amplitude Operator (RAO) for various wave periods obtained from numerical and model tests is reported in Figure 4 for free floating operating condition without central conduit (Vishwanath and Jalihal, 2022). Peak response is observed at 20 s period. Two plots show a difference of about 15 % for mid period range (10s-18s) but are reasonable match for rest. Appropriate operating and survival environmental conditions were considered for the platform design for a life period of 25 years. The environmental conditions and the summary of extreme motions is shown in Table 2.

Mooring system

The platform is considered to be permanently moored at the location in 1000 m water depth for a design life of 25 years. The design acceptances are checked as per API RP 2 SK, 2005. The mooring system is analysed according to design criteria formulated in terms of two limit states:

(i) *Intact Condition*: A limit state to ensure that the individual mooring lines have adequate strength to withstand the load effects imposed by extreme environmental actions and.

(ii) *Damage Condition*: A limit state to ensure that the mooring system has adequate capacity to withstand the failure of one mooring line.

The hydrodynamic panel model, consisting of pontoon, four columns and the central conduit stiffening structure surrounding the supply/ discharge water conduits was used for the mooring analysis. Each mooring line is a combination of chains and polyester rope of appropriate lengths. The analysis was performed in the time domain in commercial software. Extreme values were estimated from a computer simulation time of 3 hours time period. Platform is permanently moored at 1000 m water depth. Symmetrical 8 point taut mooring arrangement is recommended as shown in Figure 5. Eight headings from 0° to 315° degrees at each 45° interval are considered for the analysis. Wind and current directions are assumed to be same as wave direction (worst case). The mooring arrangement was optimized through: (i) Mooring pattern (line arrangement and spread angle and layout), and (ii) Chain and Polyester rope grade, diameter and length of each segment of the mooring line.

Pipelines

High Density Polyethylene (HDPE) pipes are considered for deep sea cold water and warm surface water for intake and discharge pipelines. Deep sea cold water pipeline is one of the most critical components for any ocean thermal gradient based energy/desalination plant. A bundle of 4 HDPE pipeline of about 800 m long HDPE pipeline of large diameter is considered for conveying deep sea cold water of temperature less than 10^{o}C from a depth of 800 m to the semi-submersible mounted LTTD plant. Table 3 shows the HDPE properties used for cold water supply, cold water dischargeand warm water discharge pipelines. HDPE conduit group consist of total 12 conduits, 4 cold water supply conduits that go to depth of 800 m below mean sea level, 4 cold water return conduits which go to depth of 140 m below mean sea level, and another 4 warm water return conduits which go to depth of 80 m below mean sea level. Figure 6 shows the conduit bundle.

Table 2. Extreme motions of semi-submersible platform

Condition	Hs (m)	Tp range (sec)	Roll (Deg)	Pitch (Deg)	Heave (g)
Operating	5.9	8.75 – 13.30	2.365	2.360	0.089
Survival	17.3	15.0 – 23.0	7.804	7.717	0.272

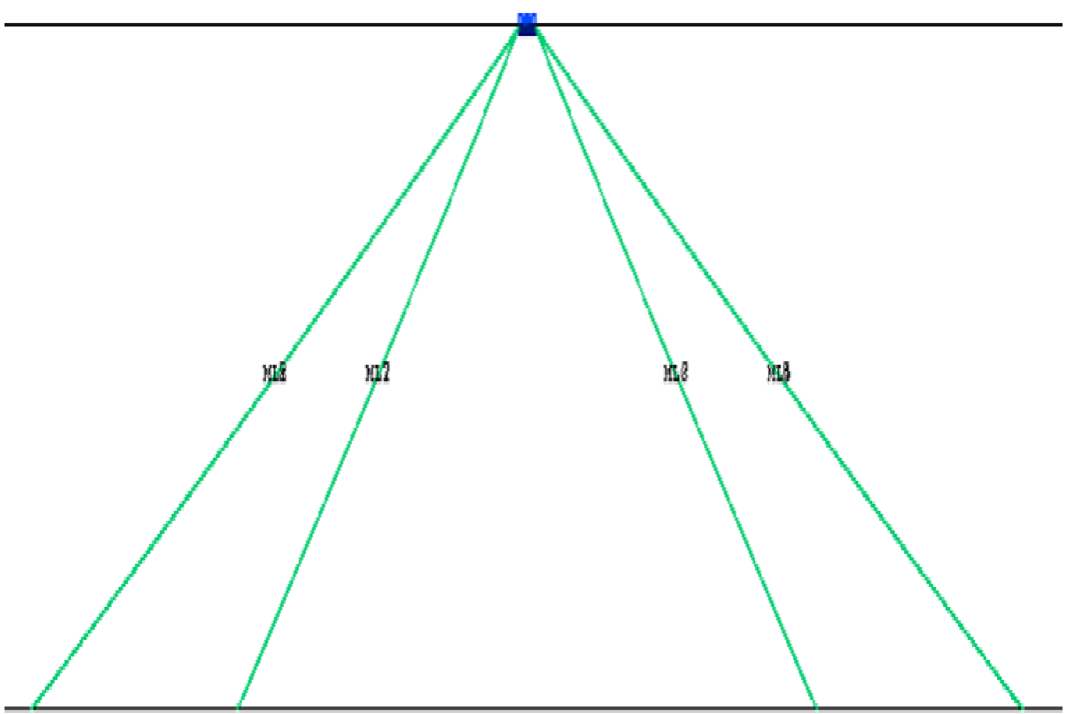

Figure 5. Spread mooring for offshore desalination plant

Table 3. Properties of HDPE pipe

Description	Value
Conduit OD (mm)	1600
Grade	PE 100
Pressure rating	PN 10
Standard dimension ratio	17
Density (kg/m^3)	930
Young's modulus (MPa)	185 (50 year life)
Yield stress (MPa)	10

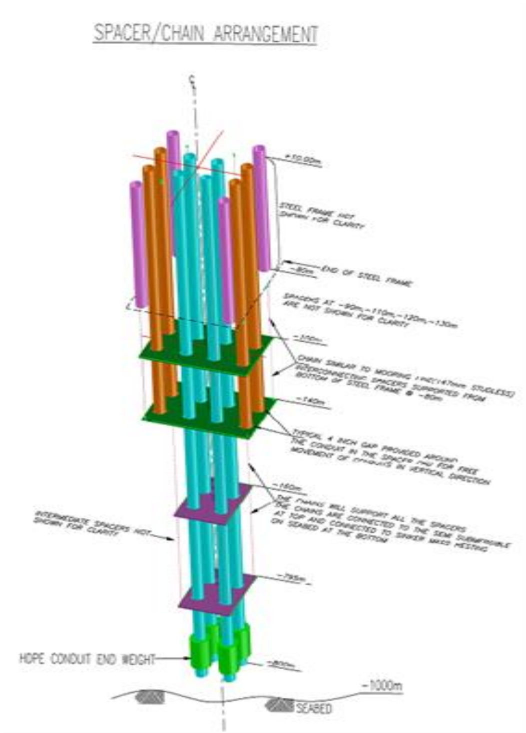

Figure 6. HDPE conduit bundle

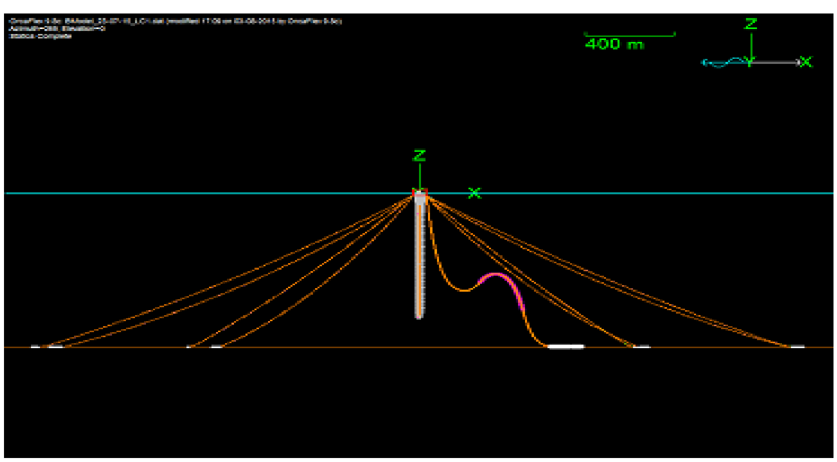

Figure 7. Snap shot of the Global In-place Model

The following major analysis and studies were carried out for the HDPE conduit and freshwater transportation pipeline design using proven commercial software's and design methods.

(i) HDPE Conduits – Global In Place Analysis

(ii) Modal / VIV / Fatigue Analysis

(iii) Loadout, Towing & Upending

(iv) Transportation of fresh water from platform to mainland using pipeline/riser configuration

(v) Design and Analysis of Connection Clamp between HDPE Conduit Bundle and Platform

The pipeline was modeled as homogenous line element with free flooding of sea water. The top end is connected to the semi-submersible and bottom end is free. Since the specific gravity of HDPE is less than 1, the pipeline overall needs to be made negatively buoyant by distributing weights along the pipe length. After the addition of weights along the length, a clump weight is added at the bottom of the pipe to eliminate compression in the pipe and also to reduce the bending stresses, arising due to the motions caused by waves and current. Several iterations were performed by varying the weights and their distribution along the length of the pipe. A configuration was achieved after various iterations. The global analysis was carried out using commercially available dynamic analysis software as shown in Figure 7. The tool performs time domain simulation for predicting the behavior of the pipeline, thus evaluating the stresses, tensions, etc. in pipeline, satisfying the allowable stresses, bending radii, tension, and other criteria. An estimated 200-ton clump weight was determined at the end of the cold-water conduit based on the analysis.

The transportation of fresh water is by combination of flexible riser from plant to seabed and rigid pipeline from there onwards to the main land for distribution. The length of the rigid pipeline is around 41km. The proposed flexible riser will pass through a tube attached to offshore LTTD Plant. The flexible riser is held in position at one end by a dead weight clamp at platform deck level and other end is connected to pipeline end manifold resting on seabed. The offshore rigid pipeline starts from the pipeline end manifold and terminates at onshore fresh water receiving terminal. Flexible pipe of 12 inch inner diameter of appropriate material for riser and 14 inch outer diameter pipe made of carbon steel is selected for the pipeline. The fresh water delivery system is designed for the functional and environment loads. For the operation phase, the system is designed for 100-year return period storm whereas for the installation phase, 1 year return period storm is considered. A detailed design was carried out for various components of thermal process, floating platform, piping, pipelines, electrical and instrumentation, costing, etc. The platform design is also CLASS certified. The design is now ready to be implemented.

CONCLUSIONS

NIOT is attempting to scale up the Low Temperature Thermal Desalination (LTTD) technology for augmenting mainland and island fresh water requirements. After successful demonstration of 1 MLD barge mounted LTTD plant, NIOT now is proposing to install a floating LTTD plant of 10 MLD capacity. Experiences gained from the earlier LTTD demonstrations, helped in design of large capacity offshore plant. Considering the large size of all components and it being the first ever such plant, and also having a major emphasis only on the offshore component, it seemed prudent to carry out detailed study of critical offshore components. A permanently moored semi- submersible platform (~26000 tons displacement) in 1000 m water depth, suitable for all weather conditions, was designed to house the LTTD plant equipment. Major emphasis on optimization of platform, moorings and critical sea water pipelines were given to come out with a viable plant design for a life span of 25 years. Various iterations were carried out to finalize layout and configuration of moorings and pipelines. The design of these components was carried out as per offshore industry practices and standards. If implemented, the 10 MLD plant will be a big boost to Indian shipping industry.

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Author Credit Statement

A Vishwanath: Data compilation, formal analysis, mapping, interpretation, and manuscript preparation; and P Jalihal: Planning, interpretation and critical feedback to strengthen the manuscript; and A Sajjan: formal analysis and manuscript preparation

Data Availability

Data is based on internal study. It may be made available on reasonable request.

Compliance with Ethical Standard

All of the authors have read the manuscript thoroughly and confirm that it has neither been submitted to any other journal and nor been considered for publication. All authors have been actively involved in substantive work leading to the manuscript and will hold themselves jointly and individually responsible for its content. Authors adhere to copyright norms

REFERENCES

API RP 2 SK, 2005. Design and Analysis of station keeping systems for floating structures.

Halkyard, J., Chao, J., Abbott, P., Dagleish, J., Banon, H. and Thiagarajan, K., 2002. A deep draft semisubmersible with a retractable heave plate. Offshore technology conference, Texas, USA, pp. OTC-14304.

IMO MODU 2009. Code for the Construction and Equipment of Mobile Offshore Drilling Units.

Jalihal, P., 2022. Sustainable technologies and interventions for alleviating water stress in coastal and island communities. J. Ind. Geophys. Union, 26(4), 362-373.

Minkenberg, H. L. and Van Sluijs, M. F., 1972. Motion optimization of semi-submersibles. Offshore Technology Conference, Texas, USA, pp. OTC-1627.

Rognoni, M.,Kathiroli, S. and Jalihal, P., 2008. Low Temperature Thermal Desalination (LTTD): new sustainable desalination process. Int. J. Nuclear Desalination, 3(1), 69-78.

Vishwanath, A., Jalihal, P. and Sajjan, A., 2020. Studies on nonlinear behaviour of floating components for offshore desalination plants. Curr. Sci., 118(11), 1694-1701

Vishwanath, A. and Jalihal, P., 2022. Studies on platform configurations for offshore energy and desalination applications. OCEANS 2022, Chennai, India, pp. 1-8.

Voogt, A. J., Soles, J. J. and Dijk, R. V., 2002. Mean and low frequency roll for semi-submersibles in waves. International Ocean and Polar Engineering Conference, Kitakyushu, Japan, pp. ISOPE-I.

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