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Research paper

Design and Testing of A Novel Ocean Thermal Energy Conversion System

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Abstract

This study addresses the theoretical model, computational simulation, and experimental outcomes of a hybrid system that integrates Ocean Thermal Energy Conversion (OTEC) and Direct Contact Membrane Distillation (DCMD). The system employs a closed-cycle OTEC configuration designed with As-pen Plus and Pro-E software and utilizes R134a as the work fluid. When interfaced to DCMD, there is a remarkable enhancement in thermal efficiency, from 2.19% to 25.38%, based on experimental findings. In addition to power production, the system can also provide an extra about 58.874 tons of freshwater per day. The use of this multi-functional platform in tropical island environments with strong thermal gradi-ents is highly feasible. We further explain some of the main challenges and opportunities for a large deployment.

Keywords: *Ocean; Thermal Energy; Ship; Conversion; Marine.*

1. Introduction

Ocean Thermal Energy Conversion (OTEC) is a new and novel renewable energy technology that utilizes the difference in temperature between the surface of the ocean and the bottom waters to generate electricity. Its significance has grown in the tropical island and coastal societies because of expanding demands for electricity and freshwater. Closed-cycle OTEC has been of most interest among the various types since it generates power and freshwater, and it is of most value when integrated with the desalination technologies like Direct Contact Membrane Distillation (DCMD). However, there are formidable barriers to mass deployment, which include corrosion of materials, limitations on efficiency, and the deep-water pipe infrastructure.

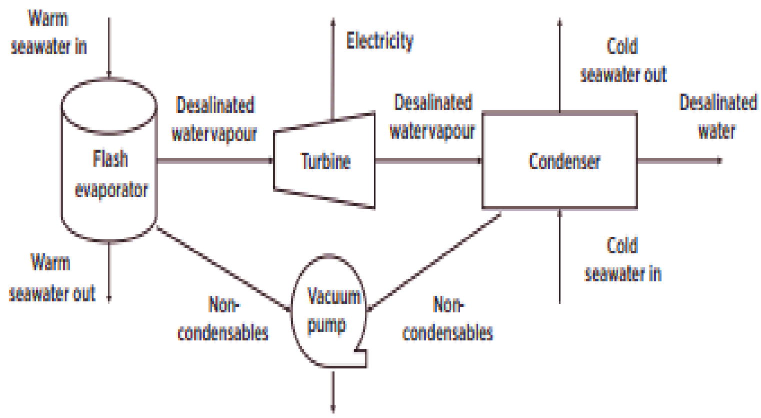

Fig. 1: Open Cycle OTEC.

Depending on the modes of cycles they run with, ocean thermal energy conversion (OTEC) systems are open, closed, or hy-brid. Due to its scalability and flexibility, the closed-cycle one is one of the most prevalent types. The organic Rankine cycle (ORC) is one of the widely used types of the closed-cycle OTEC system for electricity generation on the basis of low-grade thermal energy. It is an easy and widely used green energy technology [8]. This cycle works on R134a as the refrigerant. The authors have put long time and effort in the investigation of thermodynamic performance of the different refrigerants under ocean thermal energy conditions. The most widely used refrigerants used in laboratory and demonstration machines all over the world are ammonia and R134a [12]. Ammonia is highly efficient but carries high chances of chemical accidents as it is toxic, caustic, and volatile [16]. Due to their high thermodynamic performance and lower global warming potential (GWP), natural refrigerants such as CO_2, propane (R290), and isobutane (R600a) have also been considered in recent research for OTEC applications in addition to R134a and ammonia. However, operational stability and flammability are an issue. Hasan and Dincer (2020) concluded that CO_2 systems could function similarly but should be equipped with suitable designed components to be used safely in marine operations. In fact, R134a overall performs quite well. Moreover, besides being chemically stable, it does not possess the characteristics of being combustible, explo-sive, poisonous, irritating, or corrosive and has no chemical reactions with metals like iron, cop-per, and aluminum. Moreover, R134a does not deplete the ozone layer and is hence ozone-safe. One of the most commonly utilized refrigerants, R134a belongs to A1-class, i.e., the safest class, and is claimed to have first-class safety and environmental characteristics. R134a was experimented on various US and Japanese demonstration power plants [10]. Even though the relatively large size of the cycle system circulating agent dose experimental test platform, R134a was chosen as the circulating agent for reasons of safety and environmental protection. It employs Aspen Plus V10 to select a suitable water immersion screw chiller to satisfy the 4 °C and 28 °C heating and cooling source conditions, respectively. A 3D packaging trial platform is simulated with Pro-E 5.0 to ensure space optimization [5] after equipment selection.

2. Description of the integrated OTEC-DCMD system

Subjective and objective factors both play their part to render ship structures indeterminate. Since the designer is unaware of the wave pattern leading to structural collapse, subjective uncertainties, or modeling uncertainties, take place. The most prevalent form these assume is below-par analytical models based on erroneous assumptions to create a pragmatic solution. There were ample OTEC projects throughout the post-2000 era. The general objective of these schemes is to explore the feasibility of utilizing tropical island systems for power and cooling. OTEC exploits temperature gradients, usually a minimum of 20 degrees Celsius, between the top surface layer and bottom layers of the ocean (800–1,000 m) [13]. The Commonwealth Scientific and Industrial Research. Organization (2012) discovered temperatures at a kilometer depth are quite stable at about 4° C, thereby making OTEC efficient under the average surface temperature of approximately 25°C.This small temperature difference can be used to produce beneficial electrical power using heat exchangers and turbines. A flash evaporator of an open cycle turbine or a heat exchanger uses saltwater that is warm as a working fluid to get vapour pressure. The vapor is then used to drive a turbine-generator to produce ener-gy for the sole purpose of creating it. Utilizing a heat exchanger, this process employs deeper, colder water from the sea to chill and condense the working fluid vapour as it exits the turbine.

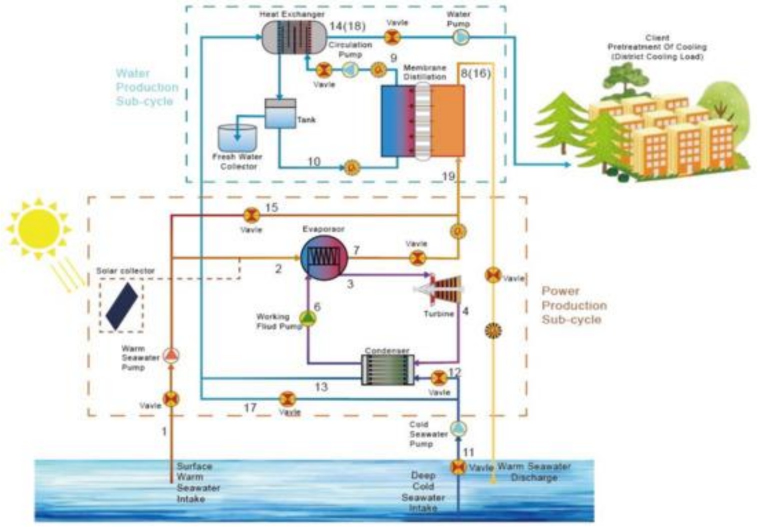

Fig. 2: The Planned Integrated Ocean Thermal Energy Conversion (OTEC) System Is Shown Schematically.

The energy assistance needed by the pumps is derived from the gross power output of the OTEC electricity generation plant. Aside from delivering cooling with no use of power, OTEC has the benefit of being able to deliver electricity continuously and without interruption. With a capacity factor of 90% to 95%, OTEC electricity generating plants are some of the most efficient power generating technology. Because fuel is "free," OTEC can operate even at the Carnot cycle's dismal efficiency (up to 7%). There is pump-ing energy loss of 20% to 30%. According to Cooper, Meyer, and Varley (2009), one of the largest technological challenges is the moderate temperature gradient, for which the flow of vast amounts of water with low pressure loss is required. A few of the major limitations of DCMD-based desalination, according to a range of recent reports, are low permeate flux, temperature polarization, and membrane fouling. Improvements in efficiency and longevity are on the horizon in the form of new materials for membranes such as electrospun nanofibers and ceramic composites. Researchers are presently working on means to scale up these technologies so that they may be combined with OTEC technology. Seawater pumps, piping systems, and large cold-water pipes have to be in good working condition in extremely severe corrosive environments for this to occur [7].

3. Platform principle and thermodynamic calculation

These stress values and deflec-tions caused by hull beam realization are approximated by global strength analysis in regard to the large global loads acting on the hull in the wave and still water states. These consist of longitudinal bending moment, hogging and sagging, shear force, and torsion moment. One example of such an evaluation is a local strength analysis where a small section of a ship structure that is directly subjected to loading, or a defined structural component when the entire ship is experiencing global loads.

A ship can be envisioned as a complete system but not by sacrificing its uniqueness as a building. Therefore, despite the huge computational expense, the ship structure must be calculated as a hull module and not structural components or close identical structural units [Hughes]. Therefore, a ship's hull module is utilized in ship structure representation studies [14].

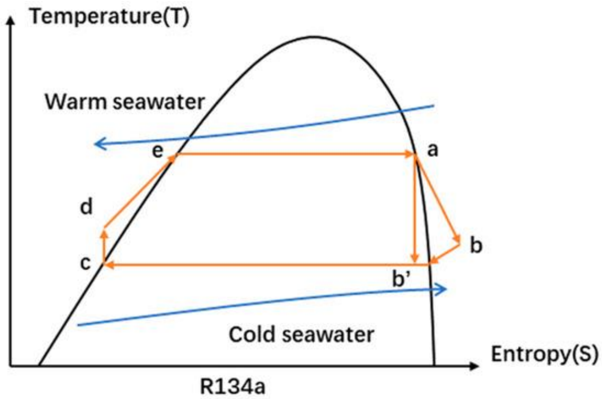

Fig. 3: Temperature–Entropy Diagram of R134a.

For the closed-cycle OTEC system, Figure 3 illustrates the R134a Temperature-Entropy (T-S) diagram. The cycle illustrates major thermodynamic states such as evaporation, expansion, condensation, and compression. It graphically illustrates component-to-component possible heat transfer and efficiency limitations. Figure 4 illustrates the system thermodynamics calculation optimization method. Innovation problems: Pumps, turbines, heat exchang-ers, platforms, and modularity enable OTEC power plants to be up to 10 MW size but growing beyond 100 MW is riddled with several challenges. To date, we have not built 10-meter diameter pipes for cold water for 100 MW power plants.

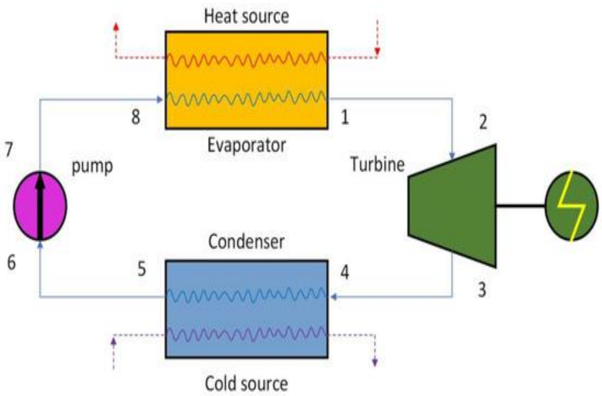

Fig. 4: A Schematic Diagram of Organic Rankine Cycle.

The better news is that technological advancements in the offshore industry can spur and de-risk the installation of higher-scale OTEC systems [4]. Different studies take into account OTEC byproducts, which may render OTEC economically sustainable [9]. Potential by-products may be lithium, hydrogen, and other rare earth minerals. Two sustainable alternatives to increase sea surface temperature are oceanic solar ponds or onshore solar thermal heating.

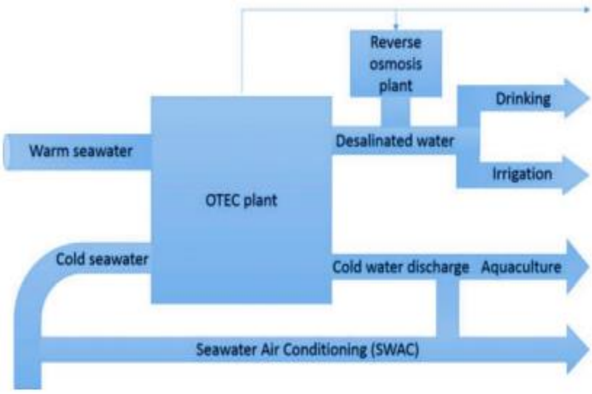

Fig. 5: Multifunctionality of an OTEC Plant.

Therefore, they are more effective and consume less energy. Installation and study of screw full-liquid chillers on an industrial level are becoming increasingly popular. [15].

New engineering challenges are arising, especially for constructing cold-water pipes larger than 10 m diameter and constructing safe offshore platforms, as OTEC technology moves toward higher capacity, i.e., 100 MW. Modular construction methods, coupled with corrosion-resistant materials such as titanium alloys and high-density polyethylene (HDPE), can significantly improve dependability while reducing cost in the process. Such huge projects can be even better securely deployed by transferring technology from offshore wind and oil industries.

Apart from the technological innovation, such a proposed OTEC system with desalination is a worthwhile resource to solve freshwater deficits on tropical islands. With the reduced use of fossil fuels and imported water as potable water, the systems can have remote places become environmentally viable. Such systems have to be considered by policymakers and utility planners in the formulation of national water infrastructure and renewable energy plans.

4. Experimental results

During operation of the system, the temperature and rate of flow of the cold and warm seawater are shown in Figure 6. Figure 6 illustrates the complete operation of the system, from startup to the end with stable operation and shutdown. In equilibrium, the operation of the system stabilizes, as can be seen from the stability of the graph. The input flow and temperature need to be held constant for maximum operation of both the OTEC power cycle and the DCMD subsystem for desalination.

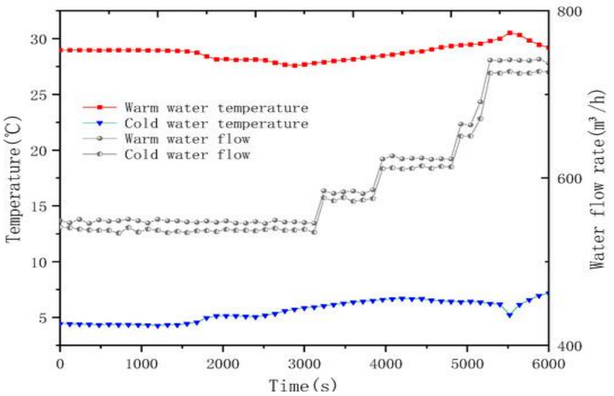

Fig. 6: The Input Working Conditions of the Power Generation System.

By applying free-free boundary conditions and classical beam theory, one-dimensional quasi-static analysis is now the most simplified approach to hull girder analysis. Portal frame analysis in this paper has been included in the transverse strength calculation.

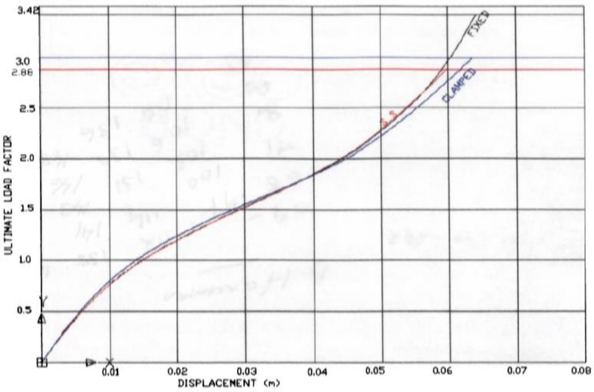

Fig. 7: Geometric Nonlinearity.

But these idealizations are not only to the hull form. Equally crucial and relevant is the study of local behavior in structures as it is to model global behavior. Two commonly used structural analysis models include the gril-lage model and the orthotropic plate model. Finite element software has been used by ship structural analysis since the late 1960s.

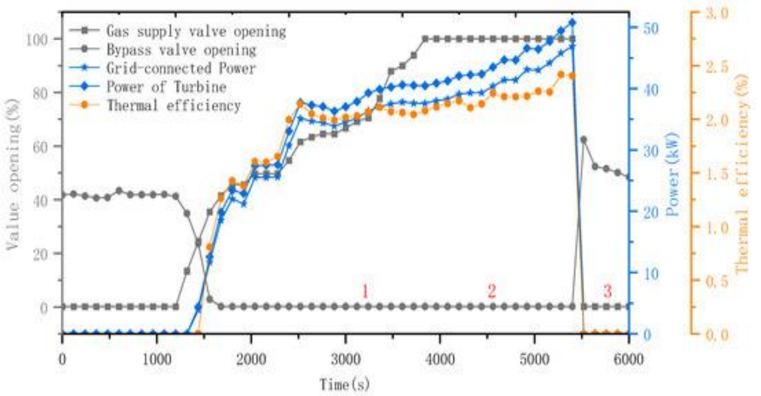

Fig. 8: Changes in the Experiment's Output Parameters.

Once Process 2 is at a steady running level, it can be changed by modifying the input parameters and system's output parameters will remain within tolerable limits without extreme oscillations. Shutdown can be performed quickly to force the experimental setup into shut-down, unlike the startup process and valve opening control.

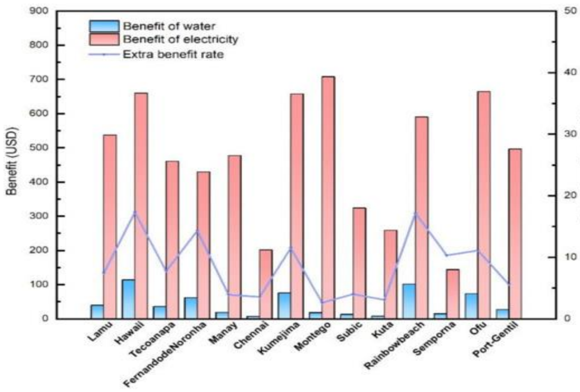

Fig. 9: Daily Benefit of Water and Electricity in Different Regions (Dry Steam).

The hold model of the battleship is examined critically for reliability using the ultimate load factor method of geometric and material non-linearity. The Young's modulus and the side shell thickness are taken as the random variables. We have employed the First Order Dependability Method to determine B, the reliability index, and pf, the failure probability.

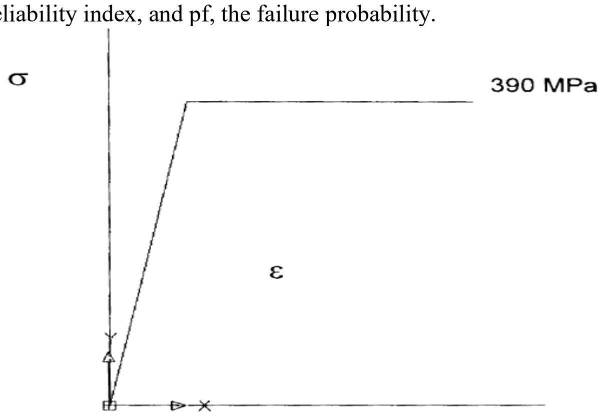

Fig. 10: Stress Strain Curve.

At the time of initial setup, the system operates normally and efficiently with little setting adjustment. Once it reaches the steady operation period, we make sure all parameters are within the accepted range. In this way, we can minimize oscillations and provide a stable shutdown.

5. Conclusion

We will design heat exchanger materials that are optimized for better system reliability and safety, and test more environmentally friendly refrigerants in the future. Progress in membrane technology, high-flux and anti-fouling materials—will also tend to provide greater long-term reliability of the integrated desalination systems.

Apart from further enhancing the reliability and efficiency of the hybrid system, OTEC-DCMD plants can be powered by offshore wind or solar energy. Artificial intelligence-based or real-time sensing-based automated control systems can provide enhanced operation efficiency and fault detection, facilitating easier large-scale deployment in varying ocean conditions.

Computational fluid dynamics (CFD) simulation and thermal dynamic analysis were performed to assess the performance of the system. From the outputs, it is possible to identify that the OTEC system would considerably enhance its thermal efficiency from 2.19% to 25.38% if DCMD desalination is utilized within the system. The system also has the potential to produce approximately 58.874 tons of fresh water daily with the aid of a 100 kW OTEC power generation cycle. Its water conversion rate is identical to that of the low-pressure flash process and can be operated using a very small footprint. Incidentally, higher water production will make any project financially more viable by as much as 20%, especially in geographically well-favored sites such as Rainbow Beach or Hawaii.

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