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Peer Review on Ocean Thermal Energy Conversion

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Abstract:

Renewable energy technology, OTEC harnesses the difference in temperature between the surface and deep ocean to generate useful electricity. Unlike solar PV and wind energy, the feedstock can be supplied continuously for day and night. The basic concept, main types, how they work, key components, advantages, uses and challenges are discussed in this paper. In a closed cycle system, a secondary fluid is processed in a loop of evaporator, turbine, condenser and pump which has a low boiling point. Open cycle systems involve the flashing of the heated seawater to generate desalinated water. Hybrid system generates both electricity and water. Thermodynamics are discussed as there is little temperature difference causing low theoretical efficiency. Important design considerations are heat exchanger performance and pumping power. The different plant designs are reviewed ranging from land based, shelf mounted and offshore floating. The pipe work in deep water, working over and under materials that resist corrosion, the prevention of biofouling and mooring and working in a marine environment are all key areas. The benefits of OTEC are the continuous low carbon electricity, freshwater production, cold seawater for air conditioning, cold seawater for aquaculture and other applications. The challenges are high capital costs, high volume of seawater, and unpredictable environmental factors with few commercial demonstrations in the long run. Ultimately, OTEC should be considered as a site-specific solution when considering marine energy solutions. Accurate net power calculations, reliable marine infrastructure, careful environmental considerations, and utilizing the electricity and seawater products together, will help the technology. The quality of resource, net power, reliability and environmental issues need to be considered. Research opportunities are discussed to allow for responsible demonstrations and deployment if the resource and the local need align.

Keywords: Ocean Thermal Energy Conversion (OTEC), renewable energy, closed cycle, open cycle, thermal gradient, Sustainability.

1. Introduction

The requirements to generate reliable electricity supply, to reduce GHGs and to reduce reliance on finite fuels are challenging the traditional energy systems across the world. This transformation is driven by a range of technologies, such as solar, wind, hydropower, geothermal, and marine energy, which all play a part but are not always available or suitable in every location and climate, nor in every infrastructure and demand. Although the direct movement of waves and tidal currents are used in some marine-energy methods, one such approach which utilizes the natural temperature difference among the ocean is called Ocean Thermal Energy Conversion (OTEC). Heat from the sun is taken up and stored at the surface of the ocean, and the ocean is much colder at great depths. The difference between these two water masses in some of the tropical and subtropical regions is large enough to make a low-temperature heat engine

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feasible. Hence, OTEC may provide a source of low cost, steady renewable energy to islands, coastal communities and offshore facilities if the thermal resource and marine infrastructure are suitable[1].

The principle is simple: one transfers heat from warm surface water of the sea to cold deep water of the sea, and a heat engine is used to extract a portion of that heat to perform mechanical work. This mechanical output is then converted to electricity by a generator. In typical designs, the surface water can be approximately 25-30 °C and the deep water can be approximately 4-6 °C, but this is subject to the variations of location, season, depth and ocean circulation. One general guideline for determining the potential suitability of a resource is a temperature difference of about 20 °C. It is not on its own an indicator of economic viability; other factors are also important such as bathymetry, grid access, wave climate, seawater chemistry, distance from shore, and the depth of cold water. Resource assessment, therefore, must take into account engineering and economic assessment along with oceanographic data[2].

The characteristic of OTEC is the relative stability of the energy source. Unlike other factors such as wind speed and solar irradiance, which may fluctuate on short time scales, the temperature structure of tropical oceans often evolves on longer time scales. Note that this does not imply constant output of OTEC: storms, seasonal variations, equipment outages and temperature difference variations as well as fouling can all impact performance. Nevertheless, there is a need to consider the potential for continuous operation for isolated islands and remote coastal facilities, where fuel imports may be costly and energy security is a significant issue. OTEC can be part of a multi-energy system mix in addition to solar, wind, batteries, and conventional generation, not a single solution for all sites[3].

There are three main types of OTEC – open cycle, closed cycle and hybrid cycle. These categories are used to represent the way the working fluid is treated, and heat is transferred. A closed cycle will maintain a closed loop of a secondary fluid with no direct mixing with the turbine fluid and seawater. In an open cycle systems the warm seawater is passed through the low pressure flash evaporator and the water vapour produced then expands through a turbine and may condense as desalinated water. A hybrid cycle represents a blend of the two with a goal of producing electricity as well as freshwater production. These can be subdivided into a wide range of thermodynamic cycles, working fluids, heat-exchanger configurations and ways of incorporating other products, such as cooling or hydrogen[4].

The assessment of environmental performances needs to be done in the construction and operation phase. Although combustion is avoided at the place of electricity generation in OTEC, OTEC is not impact free. Changes in the temperature, nutrients and biological conditions in the area can be caused by intakes and discharges and by deep water being returned to the surface. Large pipes, anchors, platforms and cables can cause disruptions to seabed habitats or navigation and fishing conflicts. Also, the materials and working fluids used in the construction of the system are important. The potential impacts will be influenced by intake design, depth and direction of discharge, pumping rates, local ecology and plant size. There are baseline surveys, careful design of diffusers, monitoring, and adaptive operating procedures that must be employed to identify and reduce risk, as well as to dismiss any notion of no environmental impacts associated with renewable energy[5].

This review presents a systematic organization of the topic from the concept to the application. It begins by outlining the primary categories of OTEC and contrasts the features in operation. It then describes how it works and how the major components work and summarises advantages, limitations and applications. The review is based on technical publications and information from public agencies on energy. Efficiencies and cost estimates reported vary by system boundaries, site assumptions and plant size so these should be considered indicative and not universal. The main message is: In appropriate oceans, and when coupled with valuable water or cooling services, OTEC has a viable place and needs to be carefully located and proven to deliver meaningful net-power and net-lifecycle benefits[6].

OTEC is similar to the technologies that extract mechanical energy directly from moving water, with the difference that it is an energy conversion technology. Gravitational and atmospheric processes drive waves and tides, while OTEC is fueled by the vertical ocean temperature stratification and the stored sun's heat. Because the ocean has a large thermal mass, it will buffer against short-term fluctuations in temperature, but the heat energy is spread out across a large area at low temperature. This poses challenges in terms of collection and conversion. The resource is not a concentrated fuel and a plant must develop a controlled heat transfer path between the two seawater streams and a working cycle. This difference is what makes the handling of the fluids and the design of the heat-exchangers part of the OTEC engineering package as well as the turbine-generator. It also describes how a favorable temperature difference could be inadequate even though deep water is not near shore and/or the power consumed by the pipe and pumping system is excessive[7].

Resource assessment is thus a multidisciplinary activity. Oceanographic data are required to define temperature profiles for the entire year, and to ascertain the depth at which a cool enough water layer exists. Bathymetric surveys are used to determine the slope of the seabed and possible intake route. An offshore platform and cold-water pipe can be safely operated with the aid of wave, current and storm data. The feasibility of the plant is the capacity to build and sustain the plant at a reasonable cost and involve the grid, port access, and local demand. The distance from the shoreline to deep water may be significant, for two different sites with the same temperature gradient may produce vastly different cost figures, depending on whether a long offshore pipe is required or a short one to the deep water. Although resource maps are very useful for screening, it is important to make site specific measurements and have a realistic plant layout for engineering feasibility[8].

Thermodynamic design is closely related to the economics. The plant requires large heat transfer surfaces and high flow rates of sea water, due to the small temperature difference. The larger the pipe diameters and/or heat exchanger surface area, the greater the heat transfer or the less the hydraulic losses will be, but the higher the capital cost and the more complex the installation will be. Smaller components can be cheaper, but can also pump more power or can be used to produce less output. This optimum design is, therefore, a system-level balance, rather than a single component maximum. Engineering and fabrication, transport, installation, marine operations, financing, maintenance, cleaning, component replacement, environmental monitoring and decommissioning should all be considered in life-cycle costs. Estimates should also provide an explanation of the assumed plant capacity, capacity factor, electricity price, financing conditions, and include co-product revenues. The cost data available from the various studies may be hard to fairly compare without the same set of assumptions[9].

2. Ocean Thermal Energy Conversion: Classification

OTEC systems have generally been divided into those that use seawater directly in the power cycle and those that use a separate working fluid in the power cycle. Both will involve the same underlying warm surface water and cold deep water, but vary in the fluid path, pressure, equipment and useful products. Besides such thermodynamic classification, plants can be categorized based on their installation location as land-based, near-shore or floating off-shore plants. Note that the two classification schemes refer to different design dimensions and are not synonymous, such as one can be installed on land or on a floating platform (closed-cycle system)[10].

2.1 Closed-cycle OTEC

A closed-cycle system uses seawater as its heat source and heat sink while a low boiling point working fluid is used. The use of ammonia is discussed widely due to its thermodynamic properties, but it is toxic and must be contained, detected, ventilated and dealt with in case of an emergency. Other potential candidate fluids also have different efficiencies, pressures, flammabilities, impacts on the environment, cost, and materials compatibility. Warm surface water from the sea is used to vaporise the working fluid in an evaporator. The vapour is passed through a turbine, which drives an electrical generator. It then goes into a condenser where the cold deep sea water extracts the heat and turns the vapour into liquid. The liquid is pumped back to the evaporator, and a cycle is completed. The seawater and working fluid are physically separate, with heat-exchanger surfaces separating them.

The use of a secondary fluid is attractive features of closed cycle designs as is the ability to select a secondary fluid with a suitable low source temperature and the fact that the turbine does not need to deal with huge quantities of low-pressure water vapour. The system is closed loop and can be controlled for proper pressure and flow and the working fluid does not need to be consumed. The principal problems associated with it are the requirement of large evaporators and condensers, sealing and leak proofing, safety of work fluids, corrosion and biofouling. Because the temperature differential is not great, a significant decrease in heat-transfer capability can cause a significant reduction in output. The heat-exchanger area, flow distribution, surface treatment, access to clean, pressure drop and pumping energy requirement to circulate both seawater streams are therefore carefully considered. The performance is relevant not in terms of the gross turbine output, but in terms of the net electrical output.

2.2. Open-cycle OTEC

In an open cycle system warm seawater is used as the working fluid. Warm surface water is pumped into a pressure vessel that is held at a very low pressure. At this low pressure, some of the water turns to water vapour at a much lower temperature than the normal boiling point. The salt and majority of non-volatile dissolved substances are left in the liquid brine, and the low-pressure vapour flows through a turbine, generating a current in a generator. The vapour

is then condensed to produce desalinated fresh water, usually with cold deep sea water. The process can then provide both electric and water power generation from the same thermal source.

By not requiring a separate refrigerant or secondary working-fluid loop, the open cycle may help to simplify some fluid management aspects, and may provide an avenue for the direct production of freshwater. But the water vapour at the very low pressure employed in the process does have a large specific volume. The turbine and vapour passages can then be large, which places operating and design requirements on maintaining the necessary vacuum. The amount of warm water that evaporates during flash evaporation is relatively small compared to the warm water input, which may be significant for the output to be useful. Net performance is influenced by air leakage, non-condensable gases, vacuum equipment and pump consumption. The rate of fresh water production also is influenced by operating conditions and is subject to proper quality testing and post-treatment for its intended application.

Open cycle plants are therefore of special interest when the value of the freshwater is high and it can be produced simultaneously with the power. Where the installation of the very large low pressure vapour handling equipment, vacuum maintenance and seawater pumping is too expensive they may not be as attractive. Not having a secondary working fluid does not mean that there are no environmental or safety concerns including impacts of the intake, the discharge characteristics, corrosion, marine growth, and the reliability of large vacuum vessels.

2.3. Hybrid-cycle OTEC

Hybrid cycle systems are systems that are a mix of selected features of open and closed cycles. In one such configuration, warm seawater is flash evaporated to generate low-pressure steam which can be used to heat a secondary working-fluid cycle. The vapour of seawater condensed can be used as a source of freshwater, the expansion of the secondary fluid through a turbine can generate electricity. Other combinations include closed-cycle power loop and open-cycle desalination stage. The specific design configuration may differ from one proposal to another so when describing a specific plant, the term “hybrid” should also be preceded by a process diagram.

Hybridization is aimed at achieving the advantages of both methods: controlled generation of power via the secondary fluid; and the potential to generate desalinated water. Combining two processes will increase equipment, controls, heat transfer interfaces, and operational interactions, but may make better use of the available thermal resource. A hybrid design is not necessarily more efficient or more economical. It is dependent on the set temperature and pressure levels, the amount of heat cascaded between stages, freshwater requirements, component sizing and the energy consumption of vacuum equipment and pumps. Net electricity and useful freshwater should be calculated together and consideration of maintenance and environmental should be included in a complete assessment.

2.4. Classification by installation configuration

Land-based or shore-based OTEC plants utilize large equipment on land with ocean pipes coming in and out. They are easier to operate, allow for existing coastal infrastructure to be utilized, and have an easy connection to local electric and water grids. The main drawback of their use is that the pipe has to be quite long and relatively large in diameter because of the deep cold-water intake. This infrastructure can be expensive due to pipe construction, anchoring, shore wave exposure and seabed conditions. A steep continental slope near the coast might be better than a shallow gently sloping coast.

Near-shore or shelf-based systems set up in coastal waters where deep water is available at reasonable distances. They might be able to relax some of their shore-pipe needs but they could still encounter issues of marine access, seabed, permitting and storm. Offshore floating systems can be deployed over deep water, and can require a shorter cold-water pipe up the vertical. Issues facing them are platform stability, mooring, dynamic loading on the pipe, corrosion, biofouling, offshore maintenance and transmission of power to the shore.

3. WORKING PRINCIPLE OF OTEC

The working principle of OTEC is that of a heat engine that is operating between a relatively warm reservoir and a relatively cold reservoir. Solar energy is absorbed and stored at the surface of the ocean, with deeper seawater being cold due to the limited direct solar radiation and its linkage with large-scale ocean circulation. Heat will transfer from the warm water stream to the cold water stream when warm and cold water streams are put in thermal contact with a power cycle. Some of this heat energy can be converted into mechanical energy, which can be used to power an electrical generator. The remaining should be spurned to the cold stream. The temperature difference is not large and the theoretical efficiency is small so losses must be minimised in the design.

3.1. Thermal resource and temperature gradient

The first step in the preliminary OTEC assessment is the ocean temperature profile. The surface water in suitable tropical regions can be approximately 25-30 °C whilst the deep water, which is obtained from several hundred metres or more, can be approximately 4-6 °C. The depth of intake will vary depending upon site and will be determined based on measured temperature profiles, bathymetry, pipe length, and pumping requirements. The usable temperature difference between the temperature of the heat exchangers is less than the difference between the inlet water temperatures due to the finite heat transfer surfaces, which necessitates approach temperatures. Normally, the warm and cold streams will be different by 20 °C at their inlet and the working fluid cannot absorb heat at the higher temperature of the warm stream, nor reject heat at the higher temperature of the cold stream. This means that real cycle efficiency is less than the ideal efficiency.

There are irretrievable irreversibilities in real equipment, and a substantial fraction of gross generation is lost in seawater pumps, working-fluid pumps, and on the plant in other portions of the equipment, where vacuum is used or by controls and other auxiliaries. The published system efficiencies are dependent on whether they are thermodynamic cycle efficiencies, gross electrical generation efficiencies or net plant output efficiencies. To make a meaningful comparison, the system boundary must be clearly defined and parasitic loads must be taken into consideration.

3.2. Closed-cycle operating sequence

Firstly, a warm-water pump draws surface seawater through an intake and pumps it through the evaporator. Second, the warm sea water will transfer heat to the low boiling point Working Fluid on the evaporator wall. The heat is absorbed by the fluid and it evaporates, and the water vapor is condensed and removed with lower temperatures. Thirdly the vapour of the working fluid runs through the turbine. The vapour does shaft work as it expands from a higher to a lower pressure. The turbine shaft is connected to a generator, which generates electricity. The turbine exhaust flows into the condenser, (4), and heats the condenser water to a temperature that satisfies the condenser requirements. The other side of the heat exchanger is filled with cold deep sea water that extracts the heat from the working fluid causing it to condense. Fifth, a pump, or a working fluid pump, increases the pressure of the liquid and pumps it back to the evaporator. This continues on and on as long as there is seawater to be tapped and plant controls to be applied in the manner prescribed.

The two seawater streams are not used to mix with the working fluid. The evaporator and condenser are then the important barriers and heat transfer devices. A leak will cause loss of performance and possibly cause an environmental or safety concern, depending on the fluid used. Temperatures, pressures, flow rates, turbine speed, electrical output, pump power, fluid inventory and alarms are typical parameters monitored by instrumentation. The control systems ensure the stable operation of the system, regulate the flow rates and operating pressures, and reduce the auxiliary consumption. Start-up and shutdown procedures are important because the low pressure cycle and the large water systems don't immediately reach steady conditions.

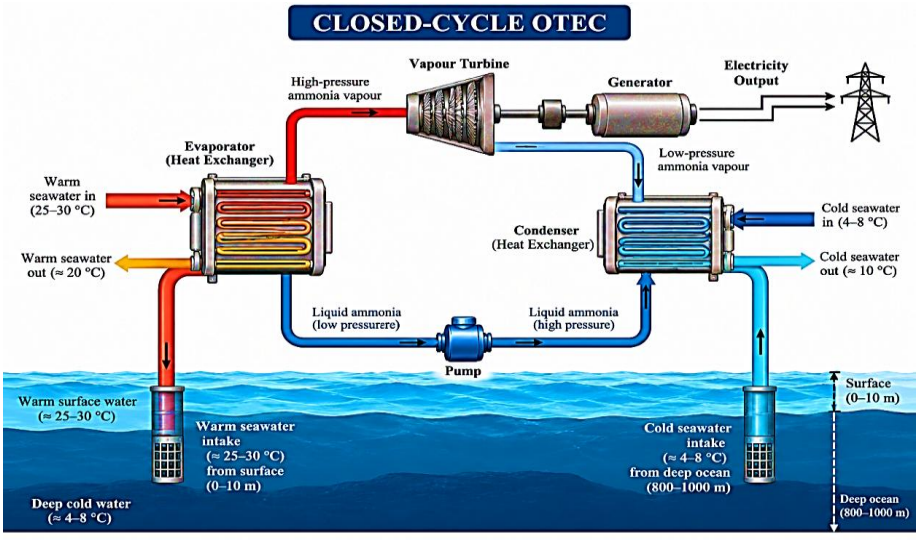


Figure 1. Closed-Cycle OTEC

3.3. Open-cycle operating sequence

In the open cycle system, warm seawater is fed into a flash evaporation chamber into which the pressure is reduced. When the pressure drops, the temperature of water drops too; in the process, a portion of the hot water quickly boils away without a separate boiler. The low-pressure steam forms a portion of the total pressure and is separated from liquid and taken to a specially designed low-pressure turbine. The rotation of the steam expands the turbine and the generator. The steam is then passed through a turbine, followed by a condenser to which deep-sea water is channeled, turning the steam back into liquid freshwater. The non-condensable gases have to be removed to keep the vacuum, and the remaining seawater stream is treated by appropriate discharge system. The open cycle is thus direct-use of seawater, and can produce a freshwater product as well as electricity.

The most important engineering challenge is the amount of space required for low-pressure steam. The turbine flow areas, ducts, vacuum vessels and condensers may be of a large size in comparison with electrical output. The flash process also only vaporises a fraction of the warm water flow, which can result in a significant portion of the power required being used to move water. The challenge in condenser design is to deliver effective heat transfer and suitable quality freshwater production. Additional testing, mineral adjustment or disinfection may be required, depending upon use. The net benefit will be influenced by the electricity generated following auxiliary loads, and whether the freshwater can be used reliably.

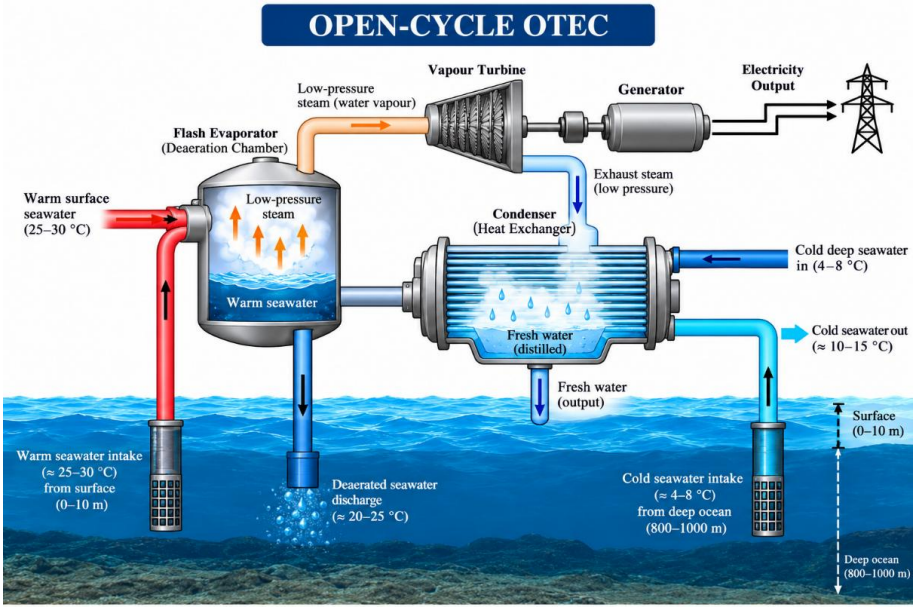


Figure 2. Open-Cycle OTEC

3.4. Hybrid-cycle operating sequence

The steam produced is then passed through another low boiling point fluid in a heat exchanger to extract the heat and then the secondary vapour is used to run a turbine. Cold seawater condense the secondary fluid back to its evaporator. In the meantime, the sea water vapour can be condensed back to fresh water. This enables a plant to benefit from the controlled turbine operation of a closed cycle, as well as the benefit of the fresh water of an open cycle. The specific configuration varies by design and a project description should specify which streams are exchanging heat and which streams are being discharged.

A whole system energy and mass balance must be performed for integration. An improved freshwater production heat exchanger can affect the power cycle's ambient water temperature, while extra pumps and vacuum equipment can decrease the net electricity produced. The engineer, then, optimizes the distribution of the warm water heat and cold water capacity between the water and power stages.

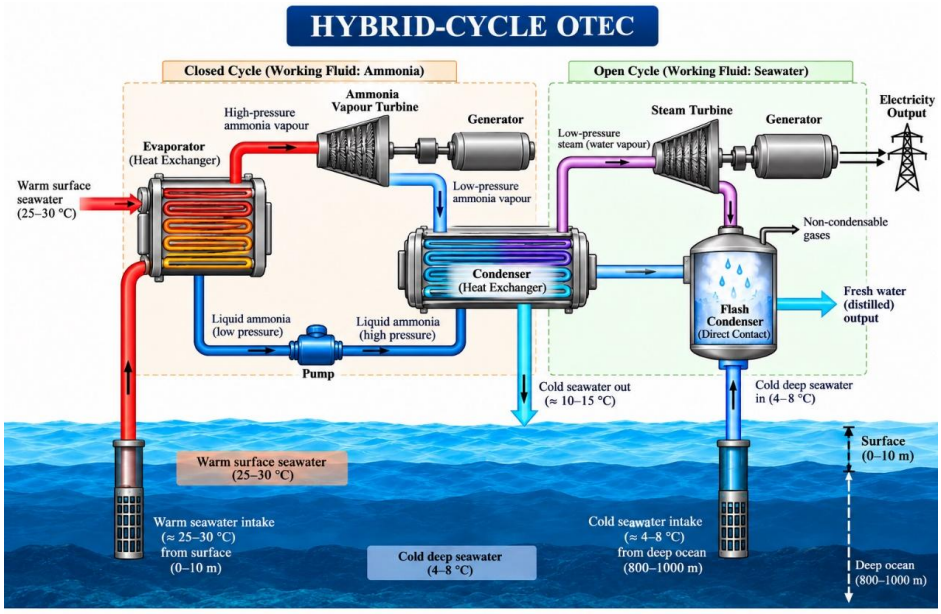


Figure 3. Hybrid-Cycle OTEC

3.5. Major components and their functions

- Warm-water intake and pump: collects surface seawater and provides the flow required to supply heat. Intake screens, placement, velocity, and maintenance affect both ecological interaction and reliability.
- Cold-water pipe and pump: delivers deep seawater to the condenser. Pipe diameter, material, length, structural support, and pressure loss strongly affect net power. Offshore pipes must withstand currents, waves, buoyancy, and cyclic loading.
- Evaporator: transfers heat from warm seawater to the working fluid in a closed cycle, or supports flash evaporation in an open cycle. Large heat-transfer area is usually needed because the temperature difference is small.
- Turbine or expander: converts the pressure and enthalpy change of vapour into shaft work. Its design depends on working-fluid properties, pressure ratio, vapour volume, and required power.
- Electrical generator and power electronics: convert shaft power into usable electrical output and condition it for a local load or grid connection.
- Condenser: removes heat from the working fluid or steam using cold seawater. In open-cycle systems, it can also produce desalinated water.
- Working-fluid pump and piping: circulate and pressurise the secondary fluid in closed-cycle and hybrid designs. Seals, valves, and monitoring systems help prevent leakage and maintain safe operation.
- Control, instrumentation, and safety systems: measure temperature, pressure, flow, vibration, electrical variables, and fluid conditions. They support start-up, shutdown, fault detection, and efficient control.
- Platform, mooring, and transmission system: offshore plants require stable support structures, anchoring, cable connections, and maintenance access. These systems influence availability and lifetime cost.

3.6. Performance, maintenance, and operating control

This is due to the fact that the thermal resource is of low quality, so that small changes in heat transfer and pumping can have a significant impact on net output. Heat exchangers must be designed to minimize pressure drop while being effective in transfer and surface areas should be inspected and cleaned to control marine growth and deposits. Several factors must be considered when selecting materials including corrosion resistance, strength, manufacturability and cost. Titanium and appropriate alloys may be used under severe sea water service conditions, however, the selection will vary based on the design and budget. Intake screens, filtration (if applicable), cleaning schedules and biofouling monitoring will help maintain performance.

One of the most critical pieces of infrastructure in the cold-water pipe. It should also have a high flow of cold water with a reasonably low hydraulic loss and should be able to withstand the effects of the ocean currents, waves and

potential storm surge. Careful control of buoyancy, bending and connection loads may be required for its installation. If there is a pipe failure or a longer blockage can cause the entire plant to be affected. Dynamic motion and mooring loads are of special concern for floating facilities.

Net output is gross generator production minus the electrical demand of warm-water pumps, cold-water pumps, working-fluid pumps, vacuum systems, controls and other auxiliaries. Maintenance, degradation due to fouling, seasonality, and outages due to unscheduled events should also be considered in the annual performance. The economic analyses shall be based on a clear lifecycle boundary encompassing plant construction, pipes, platform, transmission, replacement parts, staffing and decommissioning. Environmental monitoring needs to be incorporated within operations, particularly in the vicinity of deep water discharge, which could impact local stratification, nutrients and marine life. The well-designed OTEC system is thus a multidisciplinary marine, thermal, electrical and environmental engineering project, and not just a turbine in between two water flows.

4. Advantages

- Renewable thermal resource: uses the naturally occurring temperature difference between ocean surface and deep water.
- Potential for continuous generation: in suitable locations, the resource is less dependent on daylight and short-term weather than solar or wind.
- Low direct operational emissions: electricity generation does not require combustion at the point of operation.
- Energy security for islands: may reduce dependence on imported diesel or other fuels where local conditions support an economical plant.
- Freshwater co-production: open-cycle and hybrid designs can produce desalinated water alongside electricity.
- Cooling services: cold deep seawater can support seawater air-conditioning and other chilled-water applications.
- Multi-use infrastructure: an integrated project may combine power, water, cooling, and carefully managed aquaculture.
- Long-term resource availability: the thermal gradient is replenished by solar heating and ocean circulation, although local resource conditions still require assessment.

5. Applications

- Electricity for tropical and subtropical islands, especially where imported fuel is costly and demand is relatively steady.
- Power supply for coastal communities, ports, research facilities, and remote marine infrastructure.
- Freshwater production in locations where an open-cycle or hybrid arrangement can provide useful water quality and volume.
- Seawater air-conditioning (SWAC), using cold deep seawater to reduce conventional cooling demand in suitable coastal buildings.
- Support for aquaculture through temperature management and, where environmentally appropriate, use of nutrient-rich deep seawater.
- Integrated ocean-energy hubs that combine OTEC with solar, wind, batteries, desalination, and local microgrids.
- Research platforms for studying low-temperature heat engines, marine materials, deep-water pipes, and ocean monitoring.
- Potential future integration with hydrogen or other energy-intensive products, provided the net energy balance and economics are demonstrated.

6. Limitations And Research Challenges

- Low thermodynamic efficiency because the temperature difference between warm and cold seawater is small.
- High capital expenditure for large heat exchangers, deep-water pipes, offshore platforms, mooring, and power cables.
- Large seawater flow requirements and substantial pumping loads that can reduce net electrical output.
- Corrosion, marine growth, and biofouling that degrade heat transfer and increase maintenance.
- Engineering risks associated with long cold-water pipes, storm exposure, platform motion, and difficult offshore repairs.

- Working-fluid hazards in some closed-cycle designs, requiring leak prevention, monitoring, and appropriate safety systems.
- Potential ecological effects from intakes, discharges, construction, and changes in local temperature or nutrient conditions.
- Limited commercial operating history at large scale, creating uncertainty in financing, cost estimates, and long-term reliability.

7. Conclusion

OTEC is a unique technology for producing renewable electric power by exploiting the difference in temperature between warm surface seawater and cold deep seawater. The review indicates that OTEC can be divided into three types: closed cycle, open cycle, and hybrid cycle, each of which has different set of trade-offs in terms of working fluid management, turbine design, freshwater production and plant complexity. Closed-cycle systems involve the use of a separate low boiling point fluid, open-cycle systems involve flashing seawater at reduced pressure and hybrid systems attempt to produce electricity and freshwater simultaneously. The thermodynamic opportunity exists, but the small temperature difference has strict limits on efficiency and hence the design must focus on the performance of the heat-exchanger, seawater pumping and the reliability of cold-water pipes. In tropical island and coastal areas, where electricity, freshwater or cooling services are important and are available continuously, OTEC could be particularly useful. The high cost of capital, marine maintenance, biofouling, environmental risk, and limited commercial experience with long-duration deployments, however, still limit deployment. Improved site resource assessment; standardisation of reporting on net and not gross power; safer, more durable materials; better heat exchanger design; more reliable offshore infrastructure; and environmental monitoring during the project lifecycle should be focussed upon in future development. Co-products could be beneficial to the project value, if the integrated use of electricity, desalinated water and deep-seawater cooling is done, but it is necessary to have a realistic demand and lifecycle analysis for the co-product. OTEC, therefore, can be considered as a viable niche application in a diversified clean-energy system only if it can be proven technically reliable, economically transparent and managed in a responsible manner in the marine environment. To translate ideas into reliable projects, cooperation is required between the oceanographers, thermal engineers, electrical engineers, environmental scientists, coastal planners and the local communities. Pilot plants should report operating data and record unexpected maintenance or environmental problems and successful operation. This knowledge can be applied to designs that are safer, easier to maintain and more appropriate to local circumstances.

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