Indian Ocean Thermal Energy

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Abstract

This paper describes the basic principle of Ocean Thermal Energy Conversion (OTEC). OTEC is an energy technology that converts solar radiation to electric power. OTEC system uses the ocean's layers of water have different temperatures to drive a power-producing system. OTEC uses the difference between cooler deep and warmer surface ocean water to run a heat engine and produced useful work, usually in the form of electricity. Ocean is a vast renewable resource with the potential to help us produced billion watt of electricity. OTEC can also supply quantities of cold water as a byproduct. This can be used for air conditioning and refrigeration and the fertile water can feed biological technologies. This paper also deals with the current scenario of Indian Ocean Thermal Energy. This is also relates to the cost of OTEC power.

Keywords

Heat engine, Indian Ocean, Thermal energy and efficiency, Rankine cycle, Refrigerant, Hybrid cycle, Heat exchanger, Electrical generator, Turbine, Heat pump.

Introduction

Ocean Thermal Energy Conversion (*OTEC*) uses the difference between cooler deep and warmer shallow or surface ocean waters to run a heat engine and produce useful work, usually in the form of electricity.

A heat engine gives greater efficiency and power when run with a large temperature difference. In the oceans the temperature difference between surface and deep water is greatest in the tropics, although still a modest 20^{o}C to 25^{o}C. It is therefore in the tropics that OTEC offers the greatest possibilities. OTEC has the potential to offer global amounts of energy that are 10 to 100 times greater than other ocean energy options such as wave power. OTEC plants can operate continuously providing a base load supply for an electrical power generation system.

The main technical challenge of OTEC is to generate significant amounts of power efficiently from small temperature differences. It is still considered an emerging technology. Early OTEC systems were of 1 to 3% thermal efficiency, well below the theoretical maximum for this temperature difference of between 6 and 7%. Current designs are expected to be closer to the maximum. The first operational system was built in Cuba in 1930 and generated 22 kW. Modern designs allow performance approaching the theoretical maximum Carnot efficiency and the largest built in 1999 by the USA generated 250 kW.

The most commonly used heat cycle for OTEC is the Rankine cycle using a low-pressure turbine. Systems may be either closed-cycle or open-cycle. Closed-cycle engines use working fluids that are typically thought of as refrigerants such as ammonia or R-134a. Open-cycle engines use vapour from the seawater itself as the working fluid.

OTEC can also supply quantities of cold water as a by-product. This can be used for air conditioning and refrigeration and the fertile deep ocean water can feed biological technologies. Another by-product is fresh water distilled from the sea.

Advantages

1. OTEC uses clean, renewable, natural resources. Warm surface seawater and cold water from the ocean depths replace fossil fuels to produce electricity.

2. Suitably designed OTEC plants will produce little or no carbon dioxide or other polluting chemicals.

3. OTEC systems can produce fresh water as well as electricity. This is a significant advantage in island areas where fresh water is limited.

4. There is enough solar energy received and stored in the warm tropical ocean surface layer to provide most, if not all, of present human energy needs.

5. The use of OTEC as a source of electricity will help reduce the state's almost complete dependence on imported fossil fuels.

History

Attempts to develop and refine OTEC technology started in the 1880s. In 1881, Jacques_Arsene d'Arsonval, a French physicist, proposed tapping the thermal energy of the ocean. D'Arsonval's student, Georges Claude, built the first OTEC plant, in Cuba in 1930. The system generated 22 kW of electricity with a low-pressure turbine.

In 1931, Nikola Tesla released "Our Future Motive Power", which described such a system. Tesla ultimately concluded that the scale of engineering required made it impractical for large scale development. In 1935, Claude constructed a plant aboard a 10,000-ton cargo vessel moored off the coast of Brazil.

In 1956, French scientists designed a 3 MW plant for Abidjan, Ivory Coast. The plant was never completed, because new finds of large amounts of cheap oil made it uneconomical. In 1962, J. Hilbert Anderson and James H. Anderson, Jr. focused on increasing component efficiency. They patented their new "closed cycle" design in 1967.

Japan is a major contributor to the development of the technology. Beginning in 1970 the Tokyo Electric Power Company successfully built and deployed a 100 kW closed-cycle OTEC plant on the island of Nauru. The plant became operational 1981-10-14, producing about 120 kW of electricity; 90 kW was used to power the plant and the remaining electricity was used to power a school and other places. This set a world record for power output from an OTEC system where the power was sent to a real power grid.

The United States became involved in 1974, establishing the Natural Energy Laboratory of_Hawaii Authority at Keahole Point on the Kona coast of Hawaii. Hawaii is the best U.S. OTEC location, due to its warm surface water, access to very deep, very cold water, and Hawaii's high electricity costs. The laboratory has become a leading test facility for OTEC technology.

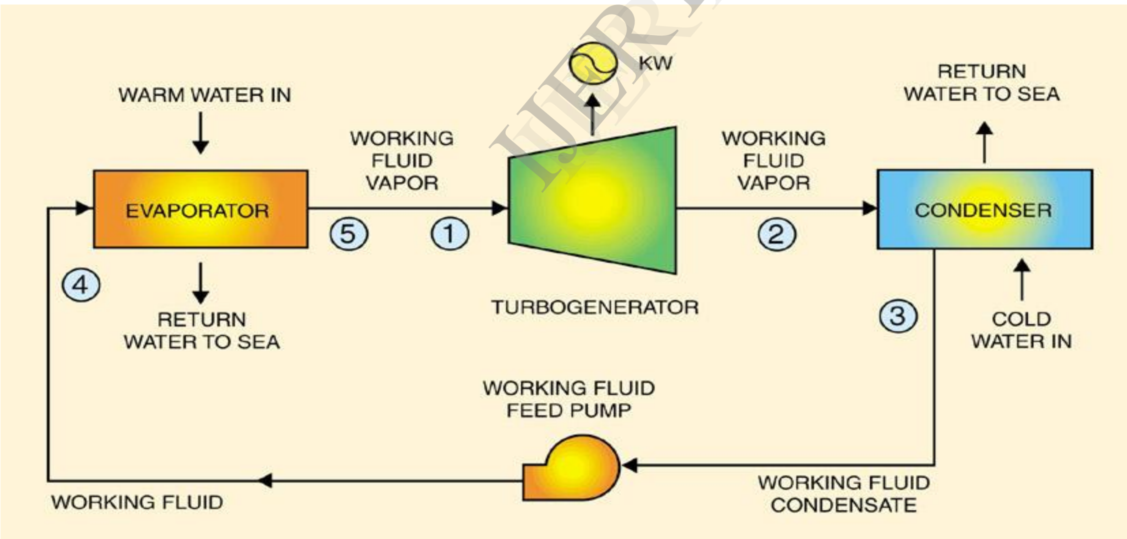
India built a one MW floating OTEC pilot plant near Tamil Nadu, and its government continues to sponsor research.

Cycle types

Cold seawater is an integral part of each of the three types of OTEC systems: closed-cycle, open-cycle, and hybrid. To operate, the cold seawater must be brought to the surface. The primary approaches are active pumping and desalination. Desalinating seawater near the sea floor lowers its density, which causes it to rise to the surface.

The alternative to costly pipes to bring condensing cold water to the surface is to pump vaporized low boiling point fluid into the depths to be condensed, thus reducing pumping volumes and reducing technical and environmental problems and lowering costs.

Closed cycle



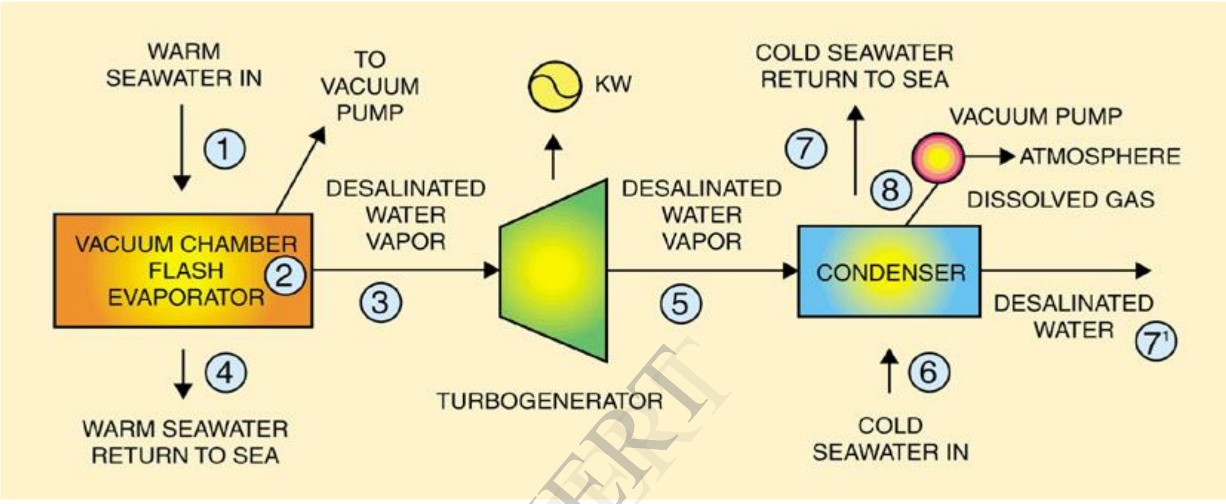
Here 1, 2,3,4,5 are the direction of flow in closed cycle diagram.

Fig.1 ***Schematic flow diagram of a closed-cycle OTEC system***

Closed-cycle systems use fluid with a low boiling point, such as ammonia, to power a turbine to generate electricity. Warm surface seawater is pumped through a heat exchanger to vaporize the fluid. The expanding vapor turns the turbo-generator. Cold water, pumped through a second heat exchanger, condenses the vapor into a liquid, which is then recycled through the system. The details process of closed cycle system is shown schematically in Fig.1.

In 1979, the Natural Energy Laboratory and several private-sector partners developed the "mini OTEC" experiment, which achieved the first successful at-sea production of net electrical power from closed-cycle OTEC. The mini OTEC vessel was moored 1.5 miles (2.4 km) off the Hawaiian coast and produced enough net electricity to illuminate the ship's light bulbs and run its computers and television.

Open cycle



Here 1,2,3,4,5,6,7,7[1],8 are the direction of flow in open cycle process.

Fig.2 ***Schematic flow diagram of an open-cycle OTEC system***

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Open-cycle OTEC uses warm surface water directly to make electricity. Placing warm seawater in a low-pressure container causes it to boil. The expanding steam drives a low-pressure turbine attached to an electrical generator. The steam, which has left its salt and other contaminants in the low-pressure container, is pure fresh water. It is condensed into a liquid by exposure to cold temperatures from deep-ocean water. This method produces desalinized fresh water, suitable for drinking water or irrigation. The details process of open cycle system is shown schematically in Fig.2

In 1984, the *Solar Energy Research Institute* (now the National Renewable Energy Laboratory) developed a vertical-spout evaporator to convert warm seawater into low-pressure steam for open-cycle plants. Conversion efficiencies were as high as 97% for seawater-to-steam conversion (overall efficiency using a vertical-spout evaporator would still only be a few per cent). In May 1993, an open-cycle OTEC plant at Keahole Point, Hawaii, produced 50,000 watts of electricity during a net power-producing experiment. This broke the record of 40 kW set by a Japanese system.

Hybrid cycle

A hybrid cycle combines the features of the closed- and open-cycle systems. In a hybrid, warm seawater enters a vacuum chamber and is flash-evaporated, similar to the open-cycle evaporation process. The steam vaporizes the ammonia working fluid of a closed-cycle loop on the other side of an ammonia vaporizer. The vaporized fluid then drives a turbine to produce electricity. The steam condenses within the heat exchanger and provides desalinated water.

Working fluids

A popular choice of working fluid is ammonia, which has superior transport properties, easy availability, and low cost. Ammonia, however, is toxic and flammable. Fluorinated carbons such as CFCs and HCFCs are not toxic or flammable, but they contribute to ozone layer depletion. Hydrocarbons too are good candidates, but they are highly flammable; in addition, this would create competition for use of them directly as fuels. The power plant size is dependent upon the vapor pressure of the working fluid. With increasing vapor pressure, the size of the turbine and heat exchangers decreases while the wall thickness of the pipe and heat exchangers increase.

There are two different kinds of OTEC power plants, which are

i. Land based power plant
ii. Ocean based power plant

These are described in detail as follows,

Land-based power plant

The land based pilot plant will consist of a building. This building will contain the heat exchangers, turbines, generators and controls. It will be connected to the ocean via several pipes, and an enormous fish farm (100 football arenas) by other pipes. Warm water is collected through a screened enclosure close to the shore. A long pipe laid on the slope collects cold water. Power and fresh water are generated in the building by the equipment. Used water is first circulated into the marine culture pond (fish farm) and then discharges by the third pipe into the ocean, downstream from the warm water inlet. This is done so that the outflow does not reenter the plant, since re-use of warm water would lower the available temperature difference.

Ocean-based power plant

OTEC needs a structure which can be commenced on the ocean surface based on the buoyancy principle is expressed here as floating power plant. The main advantages of floating power plant needs less piping and whole plant can be co-ordinate at one site instead of coordinate at sea and land as it happen land base plant.

Land-based or floating plant

The largest single item in the land based plant design is the cold water pipe. This is because slopes are seldom larger than 15° or so. This means that the length of a pipe to go down 1000 meters is equal to (1000/sin15°) which turns out to be 3864 meters. This is very large. One problem is that the pipe will be as large as 9 to 15 meters. A floating plant can have a vertical cold water pipe, which only need to be1000 meters. The fundamental reason why a land based plant costs 3 times as much per unit power output, as a sea-based plant is the expense of the cold water pipe. One advantage with the Land based power plant is that you can easier use some of the by-products without any expensive transports. For example using the cold deep water as a fluid in air condition system. It is also cheaper to support the land based.

Effective of an OTEC power plant

Theoretical, it is possible to convert the energy in a 23^0 temperature difference at an efficiency of 7-8%. In actual practice, it is possible to do this at slightly more than 3% efficiency. This not influence that the amount of power available is small, or that power generated for this source need be expensive. This energy is equivalent to the same amount of water passing through a hydroelectric dam with a water height of 56 meters. (In other words, an OTEC plant needs to handle no more water than a hydroelectric plant of the same capacity.) This temperature difference is constantly renewed by the action of the sun and the ocean currents, and is therefore inexhaustible. The amount of water constantly available for this use is enough to provide at least 300 times Mankind's total power usage. One notice, the steam locomotives, which were used during the middle of the 19th century, had a thermal efficiency of only about 3%.In order to find out the efficiency using Carnot factor the following equation can be used,

$$W = (T - T_0)/T * Q$$

W=work
T=the surface water temperature
T_0=the deep water temperature
Q=Thermal value

INDIAN SCENARIO IN OTEC

The scan of literature survey reveals that a team of engineer and scientist tested the ocean based power plant in 2009. According to Indian department of Ocean based Development’s (DOD) a one kilometer deep cold water pipeline is ready and it will be installed very soon. This pipe line is for one megawatt barge. The barge is ready and DOD team is only waiting for connect the pipe line to the barge.

It may be noted that, In May 2012 a prototype of OTEC tested by DCNS in Indian Ocean Island which is a naval defenses company based on France. In this test the following three configurations were tested by DCNS in collaboration with the University of Reunion Island’s Laboratory. The following are three configuration describe in detail,

- The first test was done with a shell and tube heat exchanger with the sea water flowing through tubes and working fluid in the shell. After the test over it is seen that the output is not comparable with other heat exchanger.

- In the second case the test was done with same as a shell and tube heat exchanger, but in this time the seawater flowing through the shell and the working fluid through the tubes to maximize the evaporation rate. In this setup some electricity consumes.

- In the third test used a plate heat exchanger that helps leaving the liquid droplet .This setup is more complicated but in the result it shows greatest thermal output.

It may be noted that the prototype is not yet connected to the sea, but the ultimate goal is in the next 20 years this technology is implemented in a new design.

OTEC ECONOMICS

It is known to fact that any project to commission the cost estimate and the span life are to be discussed .In viewing of this, an attempt is made to study the economics of OTEC.

OTEC power will be cost effective if the unit cost of power is comparable with other power Plants such as wave, hydro and diesel. However, it is important that all capital costs and ongoing maintenance/service costs are in compared on a level playing field. Work carried out by Dr Luis Vega and his team in Hawaii given in Table 1. The data given in Table 1, indicate that for plants of the 1 MW range, the unit cost is considered comparable.

Table-1 Comparison of Unit Cost of OTEC with Conventional Energy Sources in the Pacific Region (1990).

Types of Sources	Plant capacity(MW)	Plant Life (year)	*Capacity Factor (%)*	*Annual output (GWh)*	*Cost of Energy (US$m/ kWh)*
WAVE	1.5	40	68	9	0.062-0.072
HYDRA	1.2	40	48	5	0.113
DIESEL	0.9	20	64	5	0.126
OTEC	1.256	30	80	8.8	0.149

The data also indicate that the cost of energy production by OTEC will be US$ 0.149 per kWh. However the cost effect is in significant when compare to other types of sources with references to Indian energy cost per unit. Thus it is suggested that OTEC can be set up as an alternative resources for future generation by which the natural energy resources can be saved.

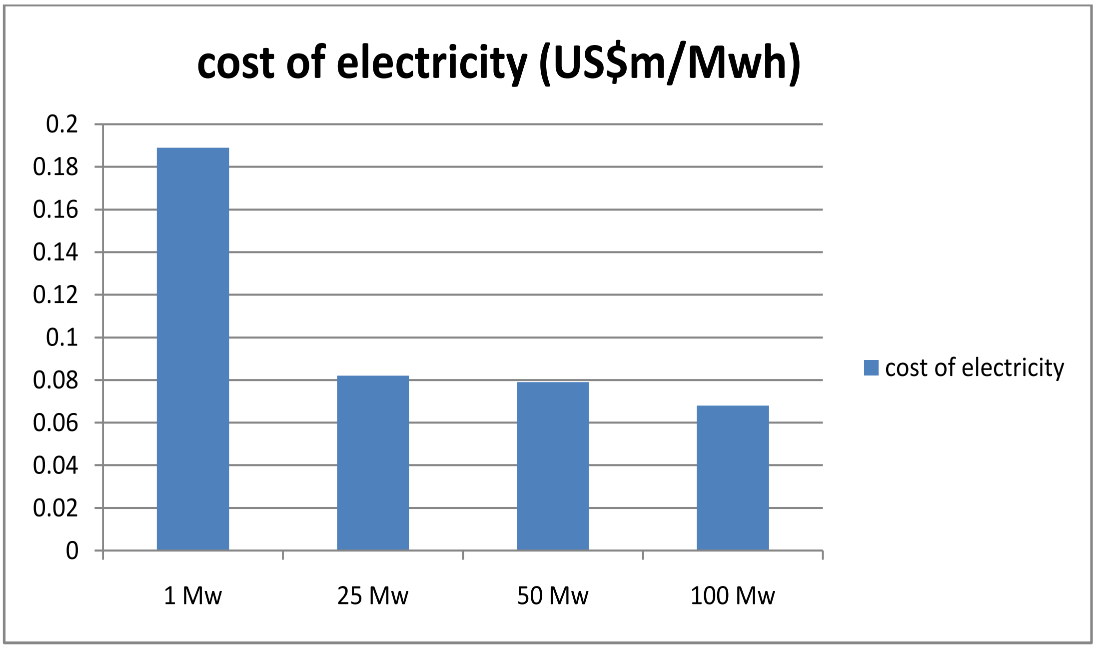
Keeping in viewing the Indian context demand on the power requirement, it is estimated to scale up to power plant 1 MW to 100 MW and accordingly the cost estimate to be presented.

The unit cost of electricity for the range of 1 MW to 100 MW is calculated and presented in Table-2.

Table-2 ***Estimation of unit cost of Electricity from OTEC power in India (1999)***

Power output (MW)	*Heat Exchanger (US$m)*	*Cost of cold water pipe (US$m)*	*Cost of Barge (US$m)*	*Turbine cost (US$m)*	*Cost of Electricity (US$m/Mwh)*
1	1.7	0.69	0.69	1.16	0.189
25	44.4	1.74	2.33	17.44	0.082
50	878	2.67	4.55	34.48	0.079
100	1256	4.55	9.33	69.76	0.068

The data given in Table-2 indicate that as expected with increasing the power output capacity of the plant the cost of heat exchanger, cost of barge, turbine cost increases but the cost of electricity comparably decreases per unit.



Power output (Mw)

CONCLUSIONS

OTEC plants are commenced and tested at different countries including Indian Ocean on land and on the sea .The following conclusions are found in OTEC plant.

- OTEC plant can generate 100MW to 500MW power.
- OTEC plant is by product such as fresh water, sea food, agricultural, commercial, ammonia, methanol etc.
- OTEC is the most benign and less risky form of generating large amount of energy presently available.
- Inspite OTEC plants are cost effective, the concept of OTEC plant are requirement as an alternative resources for future demand of power.
- The cost of energy production is in significant when compare to the other types of sources and also the cost of electricity is decreasing when the power output increases.

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