OCEAN THERMAL ENERGY CONVERSION – A REVIEW

Grishma Shedge

Electrical and Electronics Engineering, Navrachana University, (India)

ABSTRACT

Ocean Thermal Energy Conversion (OTEC) is a system that converts the temperature difference between the surface and the depth of the ocean. Since 1881, OTEC has been one of the growing renewable energy sources world-wide. This paper reviews about different aspects of OTEC generation, the trend of new OTEC technologies, advantages and disadvantages of OTEC cycle.

Keywords: *Ocean Thermal Energy Conversion, Renewable energy source.*

I. INTRODUCTION

For a human to survive, water, food and energy are the three basic amenities. Currently almost all the energy utilized comprises of fossil fuel and nuclear power.

The current world population is 7.5 billion (2017) and increasing with a steep slope. On the other hand the energy consumption is increasing as a vertical line. There is an impromptu demand for renewable sources.

In recent times solar energy and wind energy have been researched and worked upon for the forecasted energy crisis. But the drawbacks of the solar energy production like enough land space and drawbacks of wind energy production like requirement of open field are always been a hurdle to the researchers and innovators.

Comprising of 70% of the earth's body is the ocean. The ocean's potential energy is a virtually inexhaustible energy source and has been found a new track road toward the trend of renewable energy source.

In the last two and a half decades the OTEC technology has seen a brighter side. Among various energies generation techniques related to ocean, OTEC has been found in abundance and proved to be stable.

1.1. HISTORY

French physicist Mr. Jacques Arsene D'Arsonaval conceptualised the utilization of thermal energy stored between the warm surface of the ocean and cold depth of the ocean to convert into energy in 1881.

In that same year 1881, the world's first thermal power generator was made. In 1883, Mr. De Laval, a Swede, has manufactured the world's first thermal steam turbine. 1880s remained however an infant era of power generation technology in general. [1]

A student of D'Arsonval named George Claude soon took on the challenge of properly designing and building a working OTEC system. Claude, however, took a different approach to the design but could not make much progress. One of the reasons of his repeated failures can be laid on the fact that he had attempted with an open thermal cycle system. One of typical aspects

In this trend the world first 1MW class OTEC experiment project being preceded in India. In 1997 Saga University and the National Institute of Ocean Technology, India (NIOT) signed a technical agreement for a 1

MW floating OTEC plant designed by NIOT, which was then constructed in 2001. The Uehara cycle was selected for this design in order to maximize efficiency. The Institute of Ocean Energy at Saga University was founded in 2003. [1][2]

TABLE 1 History of OTEC [1]

1881	J.D'Alsonval (France) presented the Idea of OTEC
1926	G.Claude (France) started experiments of OTEC
1933	G.Claude (France) constructed on board type OTEC
1964	Anderson (USA) presented a proposal of Off-shore type OTEC
1970	New Energy Research Committee researched OTEC
1974	OTEC was researched as a part of Sunshine Project (Japan)
1974	ERDA project started to research OTEC (USA)
1974	First OTEC conference was held (USA)
1977	Saga University (Japan) succeeded to generate 1kW of power
1979	Mini-OTEC generated 50kW (USA)
1980	Saga Univ. performed off-shore experiments at sea of Japan
1981	Tokyo Electric Power Co. (Japan) succeeded to generate 120kW on Nauru
1982	Kyushu Electric Power Co. (Japan) succeeded to plant generate 50kW at Tokunoshima Is
1985	Saga Univ. completed 75kW experimental plant
1985	Kalina (USA) invented a new cycle with ammonia/water mixture technology (Japan)
1988	OTEC Association was established (Japan)
1989	Industrial and Technological Board succeeded to generate 3kW at Toyama Bay
1990	International OTEC Association (IOA) was established (Taiwan)
1993	210kW open cycle OTEC was completed in Hawaii
1994	Uehara (Japan) invented an advanced thermal cycle
2001	1MW closed cycle OTEC was constructed by NIOT (India)
2002	NIOT (India) will perform 1MW experiment
2003	25-50 system is plant by Saga University (INDIA)

II. OTEC TECHNIQUES

For OTEC there are various variants available – open cycle, closed cycle or hybrid cycle. [3]

1.2. OPEN CYCLE

Due to some disadvantages of the closed cycle OTEC plant like cost and the potential bio-fouling in the heat exchanger, Claude's came with the new concept of using only warm ocean water as the working fluid and directly using its steam to generate power. Water unlike ammonia is a non-toxic and environmental friendly.

Open cycle OTEC consists of (1) flash evaporation of a fraction of warm seawater by reducing the pressure (2) expansion of the steam through the turbine to generate the power (3) allowing the expanded steam to condense

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in the condenser with the help of the cold sea water (4) compression as well as discharge of the condensate water and also the non-condensate gases.

In this process the working fluid is discharged after every single pass. So the cycle is open. Unless there is need of using the discharged water the heat exchanger is not employed on the land in this process.

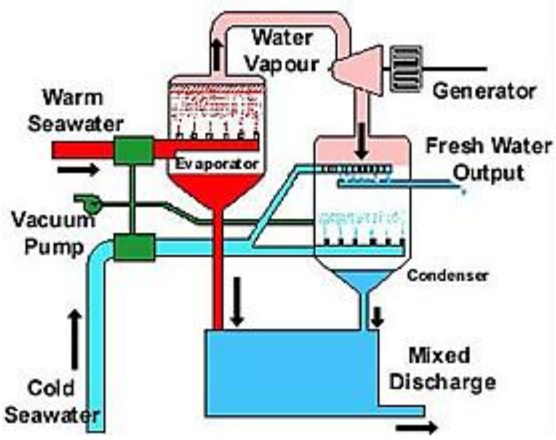

Fig. 1 Schematic diagram of Open Cycle OTEC [5]

The entire system from evaporator to the condenser works at the partial vacuum (1-3% of atmospheric pressure. At 4°C, steam condenses at 813 Pa. The turbine exit pressure cannot fall below this value. The maximum pressure drop is only about 3000 Pa, corresponding to about a 3:1 pressure ratio. [4]

The main difference between the closed and the open cycle OTEC is that in the open cycle OTEC there is the need for the complex heat and mass transfer process.

1.3. CLOSED CYCLE

D'Arsonval gave a concept of using the working fluid to generate the power which used the rule of thermodynamics. In this system, warm ocean water vaporizes a working fluid. The vapor would than expand and do work before being condensed by the cold water. This same step would repeat continuously with the same working fluid. Hence this cycle was called closed cycle.

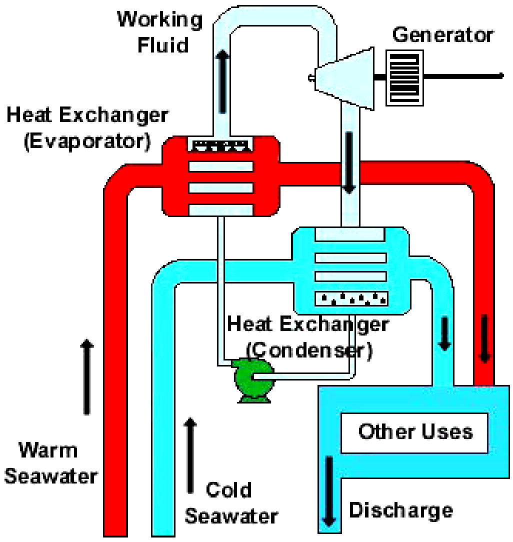

Fig. 2 Schematic diagram of Closed Cycle OTEC [5]

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The steps will include (1) in the evaporator the heat exchange will take place between the warm sea water and the working fluid. Due to the pressure generated the working fluid will heat up, boil and eventually evaporate. (2) working fluid in the form of vapor will expand and pass through the turbo generator, generating power (3) this vaporized working fluid will than pass through the condenser in with the cold sea water will allow it to get condensed quickly (4) condensed working fluid is than again allowed to flow through the same system, repeating all the steps. Here the working fluid is taken as ammonia.

Irreversibility in the turbo machinery and heat exchangers reduce cycle efficiency below the Carnot value. Irreversibility in the heat exchangers occurs when energy is transferred over a large temperature difference. It is important, therefore, to select a working fluid that will undergo the desired phase changes at temperatures established by the surface and deep sea water. [4]

The Kalina cycle is the advanced form of the closed cycle. It is also called adjustable proportion fluid mixture. In the simple closed cycle a fix amount of the working fluid is used. While in this cycle mixture of ammonia and water is taken in varying proportion at different points in the system. It provides the advantage of heat transfer irreversibility in the evaporator and condenser to be reduced with the duel degree of freedom.

The main advantage of the closed cycle is its compact size and the constant power generation.

1.4. HYBRID CYCLE

Hybrid cycle is the combination of both open cycle OTEC and closed cycle OTEC. It has the portable water production compatibility as open cycle as well as efficient and large electricity generation of electric power like that of the closed cycle.

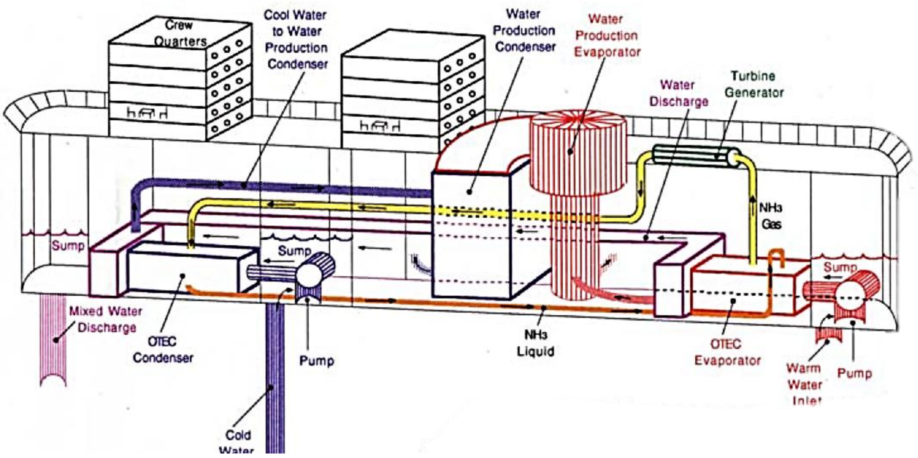

Fig. 3 Schematic Diagram of Hybrid Cycle OTEC [7]

In this cycle, both the water as well as ammonia (as a working fluid) is used. In the first stage just like Claude cycle, flash evaporation of the warm sea water takes place in the evaporating chamber due to low pressure. Now this warm water is allowed to flow in the heat exchanges where it is used to vaporize a working fluid like ammonia. During this process most of the steam gets converted into desalinated portable water. While the steam of the working fluid flows through the system following the closed cycle process. The uncondensed steam and the working fluid are further condensed and converted into the liquid ammonia in the condenser with the help of the cold sea water. The uncondensed elements are further compressed and discharged in the atmosphere.

Besides the advantage of production of both potable water and the power efficiently, it has the disadvantage that both the water producing unit and power generating unit are nearby to each other. As a result if any maintenance is required to be done in any of the units the other unit is affected. Also if there is any leakage in the ammonia line, the water may get contaminated due to it. As an alternative to it was the new hybrid power plant was proposed with de-coupled power production unit and water generating unit.

II. POTENTIAL SITES

The main thing that needs to be taken into consideration is the temperature difference between the warm surface water and the deep cold water. The temperature difference should be minimum 25°C. This condition is most of the time achieved at the 1000m depth of the ocean from the surface of the earth. There are even other factors that play important role which includes cost of fuel, present availability of electric power at the particular location and the environmental factor of the region.

As it can be seen that the temperature difference plays an important role in this process, most of the regions near the equatorial region i.e. from 10 °N to 10 °S are preferred for the establishment of the unit except West Coast of south America due to its varying temperature and climatic changes. Tropical regions from 20 °N to 20 °S are also favourable except West Cost of South America and of Southern Africa. There are physical factors playing significant role for site selection such as thermal resource and seafloor bathymetry, greatly restrict the number of desirable sites along the shoreline of major continents, unless some warm seawater temperature enhancement is possible.

The plants that have already been established and are in working condition are Ansan-South Korea which is 20 kilowatt plant, only operating during summers and Kume Island Okinawa-Japan which is 50 kilowatt plant. There are two plants which are in development one is in Hawaii with 10 kilowatt capacity and another at Martinique Caribbean with the capacity of 10 megawatt. In India at Chennai the 10 megawatt plant is being proposed.

III. ECONOMICS OF OTEC

As been discussed earlier the OTEC plant can be utilized not just for electric power generation but also for the desalinated portable water. Thus this plant holds many other applications as discussed below:

1.5. DESALINATION

The spray-flush type distillation process has been developed by Saga University. This process distills around 1% of raw sea water quantity to fresh water. For this purpose the OTEC plants need to be combined along with that of the desalination. The system size gets huge but the water that can be obtained can be utilized as a resource of hydrogen for further processes. It has been studied that the plant capacity of 1MW generates 10,000 m^3/day distilled water. Similarly plant capacity of 100MW can generate 1,000,000 m^3/day distilled water. [1]

1.6. ENERGY CARRIERS

OTEC was the process primarily developed to generate the electrical power. Due to location of the OTEC plants the storage is the main point that needs to be considered. If the storage problem is solved the energy that is being generated can be even utilized by the regions far away from the tropics.

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1.7. REFRIGERATION AND AIR CONDITIONING

The cold water from the deep sea that is been fetched for the process of condensation, can also be utilized for the process of cooling. This water can be circulated throughout the building by heat exchanger with can solve the purpose of air conditioning. The Natural Energy Laboratory of Hawaii that looks at the project of Hawaii OTEC plant have experimented such system in their unit. [4]

1.8. ACQUACULTURE

The deep sea water is cold pure and rich in nutrients. This water is favorable for the development of fishes that are found in such type of water. The cold water is utilized to cultivate oysters, lobsters, sea urchins, abalone, kelp and macro and microalgae.

1.9. AGRICULTURE

Hawaii researchers proposed an idea that involves the use of cold sea water for the agriculture purpose. The pipes carrying the cold water can be buried below the surface if the field. As a result the cold temperature is being generated for the plants that needs cold atmosphere. Also this water can be utilized for the drip irrigation purpose. This system was experimented for the plantation of strawberries and other spring crops and flowers.

IV. CONCLUSION

From literature review it is understood that OTEC works efficiently when there is required temperature difference in the ocean water. Other than generating electricity this power plant can be used simultaneously for various other purposes. The OTEC plant has many advantages and disadvantages as discussed below:

1.10. ADVANTAGES OF OTEC

- Electrical power generation
- Produces base burden electrical vitality.
- Used for the onshore as well as offshore Mari culture operations.
- Utilized for the production of the potable water (up to 5 liters for each 1000 liters of frosty seawater). [6]
- The fishes and agriculture done by this process can be utilized for the food purpose.
- The cold water is being utilized for the refrigeration purpose.

1.11. DISADVANTAGES OF OTEC

- As the site selection plays very important role due to the temperature difference requirement for the production of electric power, the plant must be established where the temperature difference must be 20°C happens year round. Also the sea profundities must be accessible for the shore based offices. Due to all this requirements there are many regions that cannot be utilized for this purpose. [6]
- Also the running and maintenance cost for the OTEC plant is more than it is required for generating power from the fossil fills.

1.12. FUTURE ASPECTS

OTEC can fulfill the essential requirements like energy, water and food in the form of fishery to the man kind for the continuation and evolution.

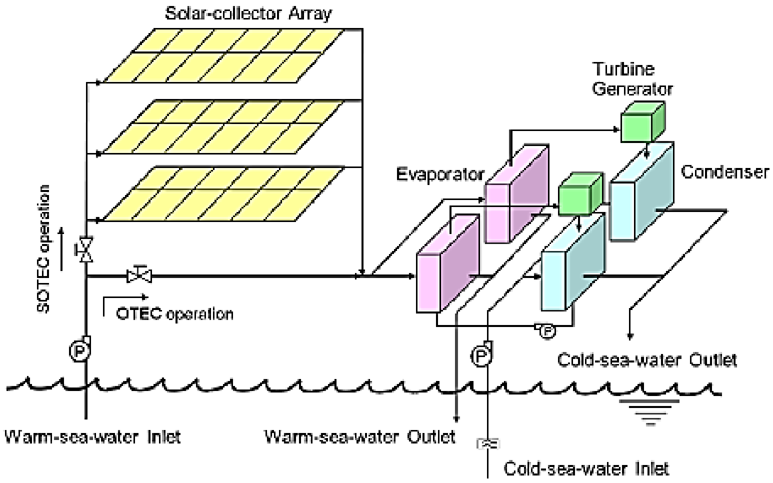

Fig. 4 Diagram of SOTEC

OTEC plant can be boosted with solar power to develop solar ocean thermal energy conversion. With the implementation of the SOTEC the thermal efficiency of the plant increases by 2.7 times than the normal OTEC plant particularly in the daytime.The development of an advanced OTEC system will become increasingly important and promising with a long-term upward trend in the prices of oil and fossil fuels.

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