Module-4b

OTEC

Syllabus:

Ocean Thermal Energy Conversion:

- Principle of working,
- OTEC power stations in the world
- problems associated with OTEC.

Introduction to OTEC

About 70% of earth's surface is covered by oceans, which are continuously heated by the sun OTEC and solar energy are typically utilized in converting low-grade heat into power generation and other applications.

Ocean thermal energy conversion(OTEC) is a method to produce electricity by using the temperature differences with warm ocean surface and cool deep ocean water to run a heat engine. If temperature difference is greater, then more energy will be produced. As long as the temperature difference between warm surface water and cold deep sea water is greater than about 20°C, an OTEC system can produce a significant amount of power.

Solar heat is stored as uneven distribution of heat between warm surface water and cold deep ocean water (called gradient) from where it is harnessed as ocean thermal energy.OTEC sites that are located between the Tropic of Cancer and Tropic of Capricorn (23.5°N and 23.5°S of equator) found to be best locations. Ocean water with temperature gradient of 5°C and more is known as ocean thermal energy.

As long as the temperature difference between the warm surface water and the cold deep water below 600 metres by about 20°C, an OTEC system can produce a significant amount of power. Thus, oceans are vast renewable resources with the potential to produce thousands of kW of electric power.

Principle of Ocean Thermal Energy Conversion

- The warm water from the ocean surface is collected and pumped through the heat exchanger to heat and vapourize a working fluid, and it develops pressure in a secondary cycle.
- Then, the vapourized working fluid expands through a heat engine (similar to a turbine) coupled to an electric generator that generates electrical power.
- Working fluid vapour coming out of heat engine is condensed back into liquid by a condenser. Cold deep ocean water is pumped through condenser where the vapour is cooled and returns to liquid state.
- The liquid (working fluid) is pumped again through heat exchanger and cycle repeats. It is known as closed-cycle OTEC
- For high temperature ocean surface water-working fluid used is ammonia, propane or similar material
- For low temperature surface water-working fluid used is ammonia with low boiling point.
- In an open-cycle OETC, warm ocean surface water is pumped into a low-pressure boiler to boil and produce steam.

- Then, the steam is used in steam turbine to drive an electrical generator for producing electrical power.
- The cold deep sea water is used in condenser to condense steam

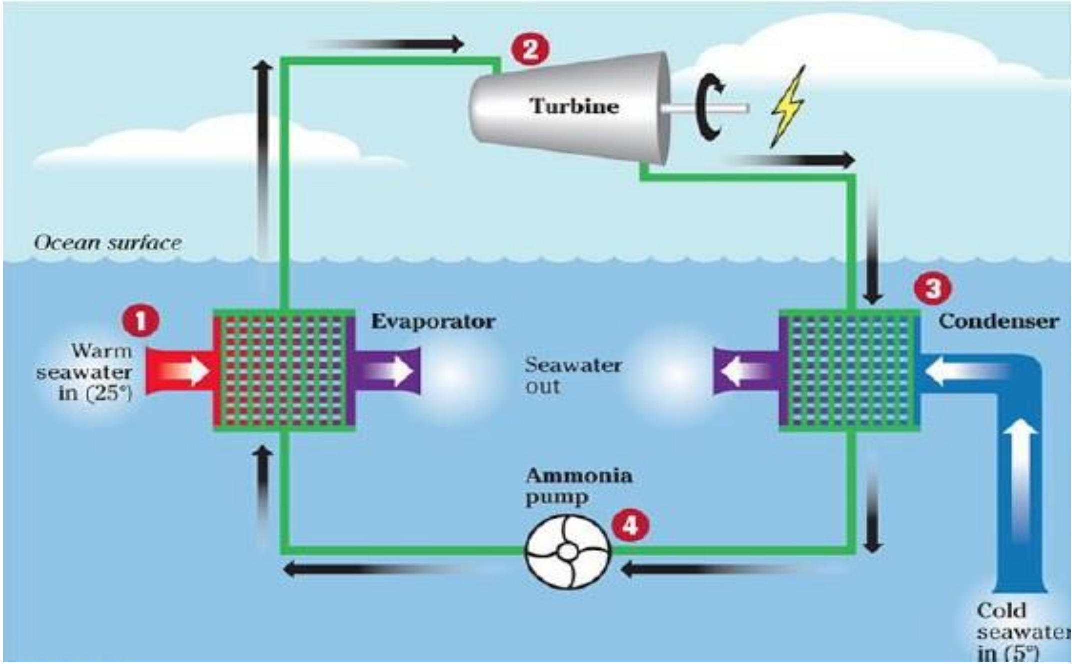


Fig: Principle of Ocean Thermal Energy Conversion

Ocean thermal energy conversion plants

1. Land based power plant- constructed on shore.
2. Floating power plant- built on ship platform where temperature gradient is sufficient.

Types of OTEC systems

1.Closed-cycle

2. Open-cycle

3. Hybrid.

In Closed-cycle OTEC systems: the working fluid, such as ammonia, is used to vaporize and condense repeatedly in a closed loop. The working fluid is kept separate from the seawater, so there is no direct contact between the two.

In Open-cycle OTEC systems: warm surface seawater is used as the working fluid, which is vaporized and then condensed by cold seawater. This means that there is direct contact between the working fluid and the seawater.

Hybrid OTEC systems use both closed and open-cycle processes. They use a closed cycle for the first step, in which warm surface seawater heats the working fluid, and an open cycle for the second step, in which the vapor is condensed by cold seawater.

Open-Cycle OTEC

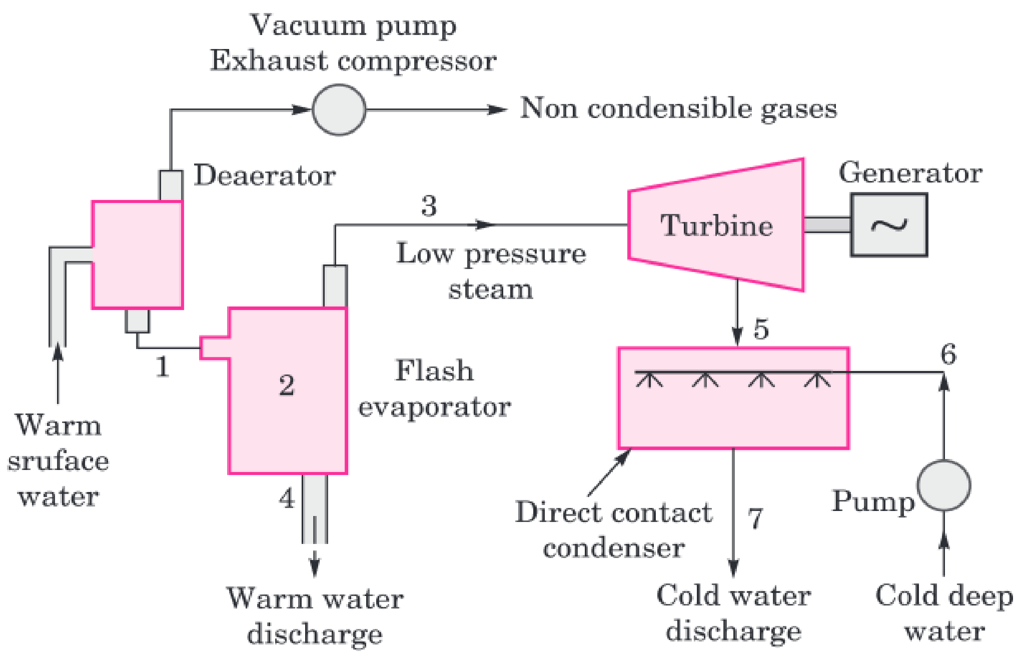


Fig. 9.1. Schematic of the OTEC open cycle.

- The working principles of open-cycle OTEC plants are explained as follows
- The warm ocean surface water is pumped into flash evaporator where it is partially flashed into steam at a very low pressure.
- The remaining warm sea water is discharged into the sea.
- The low-pressure vapour (steam) expands in turbine to drive a coupled electrical generator to produce electricity.
- A portion of electricity generated is consumed in plants to run pumps and for other work, and the remaining large amount of electricity is stored as net electrical power.
- The steam with many gases (such as oxygen, nitrogen, and carbon dioxide) released from the turbine separated from sea water in an evaporator is pumped into condenser.
- The steam is cooled in a condenser by cold deep sea water.
- The condensed non-saline water is discharged either directly in deep sea cold water or through the marine culture pond.
- The non-condensable gases are compressed to pressure and exhausted simultaneously.
- The warm ocean surface water is continuously pumped into evaporator and cycle repeats.

Closed-Cycle OTEC

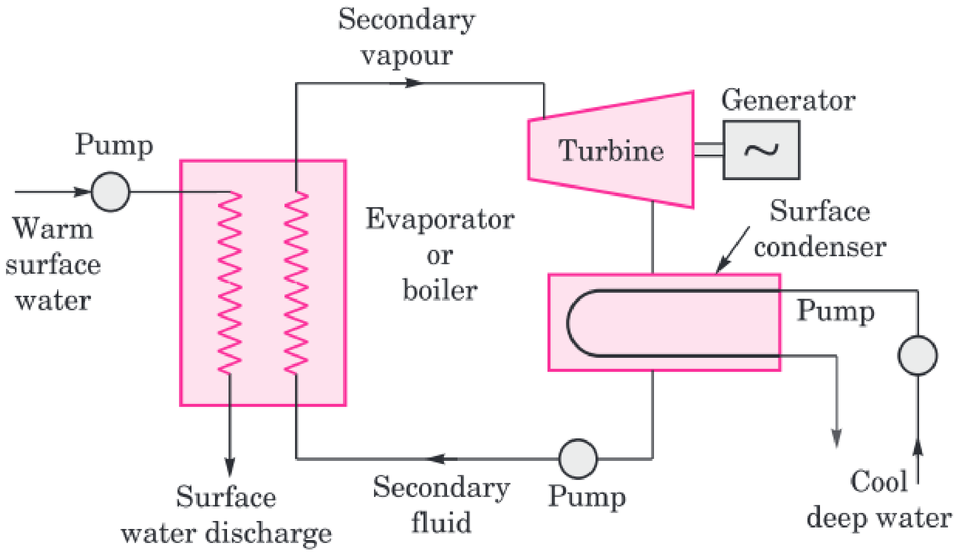


Fig. 9.3. Schematic of an OTEC closed cycle system.

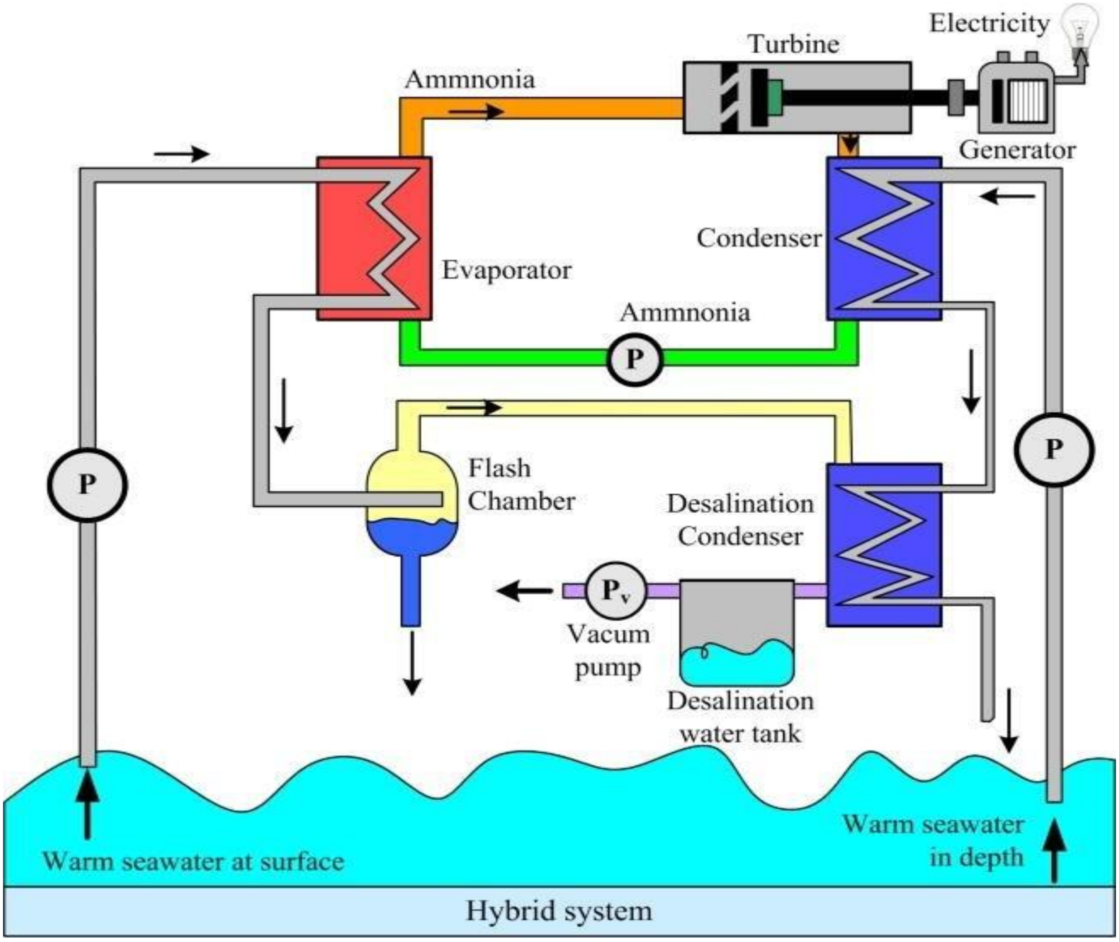
- The schematic of closed-cycle OTEC is shown. It has different arrangement when compared to open-cycle OTEC.

Working principles of closed-cycle OTEC are as follows:

- Working fluid is pumped through heat exchangers in a closed loop cycle which is perfectly leakage proof.
- Warm sea surface water is pumped through separate pipe in heat exchanger in close contact with fluid closed loop cycle.
- Warm sea water transfer its heat energy to working fluid in heat exchanger and working fluid vapourized.
- The fluid vapour makes the turbine to rotate and drive an electrical generator to produce electricity.
- Fluid vapour leaving the turbine is cooled and condensed as liquid fluid and is pumped again to repeat cycle.
- Cold deep sea water is pumped through a separate pipe in condenser for providing efficient cooling of working fluid.

OTEC Hybrid Cycle

- Hybrid cycles combines the open and closed-cycle systems. The hybrid cycle uses seawater which is placed in a low-pressure tank for steam. Then the steam is used to evaporate the low boiling point fluid (ammonia or others). The seawater vapor is then condensed to produce desalination fresh water.
- On the whole, the OTEC works when the sea heat energy conversion uses temperature differences between warm surfaces and cold deep seawater, at least 77°F (25°C).



- In the operation of OTEC, pipes will be placed in the sea which functions to suck up the heat of the sea and flow it into a heating tank to boil the working fluid. Ammonia is commonly used as a working fluid because it is volatile. The fluid vapor will then be used to drive power generation turbines.
- Fluid vapors then flowed into the condenser chamber and refrigerated by using seawater with a temperature of 5°C. The cooling water is then released back to the sea and so on, and then a repeat cycle will occur.

Application of OTEC in addition To Produce Electricity

- OTEC schematic diagram and applications are shown in Figure
- Ocean thermal converting plants provide several products for use by mankind.

***1. Electricity*:**

- Electrical energy is the primary product of OTEC plants.
- Laying down long transmission and distribution cables up to the sea shore for domestic and industrial applications is not practical from economic view point.
- OTEC plants are, therefore, considered for other products and applications.

2. Hydrogen production:

- Electricity produced from OTEC plants is used for separating water in hydrogen and oxygen by the method of electrolysis of water.
- Hydrogen is considered as the second best usable form of energy after electricity.
- Use of deep sea cold water and OTEC electricity for hydrogen production signifies the important applications of OTEC plants.

3. Ammonia and methanol production:

- OTEC electricity can be used to obtain by-products, such as ammonia and methanol, that can be transported either by tankers or through pipe lines to on shore applications.

4. Desalinated water:

- Desalinated water is produced in an open-cycle and hybrid-type OTEC plants through surface condenser.
- It is freshwater and widely used as water resource for drinking, agriculture, and industry.

5. Aquaculture:

- Nutrient-rich cold deep sea water provides sufficient environment for fish farming which may create a profitable business activities.

6. Air conditioning:

- Because the temperature is only a few degrees, cold water can be used as a fluid in air condition systems.

Advantages, Disadvantages And Benefits of OTEC

Advantages

1. Ocean thermal energy is a renewable, clean natural resource available in abundance.
2. It is pollution-free and has no greenhouse effects.
3. It is a good source of freshwater and portable water.

Disadvantages

1. ***High cost*****:** Electricity generated by OTEC plants is more expensive than electricity produced by chemical and nuclear fuels.

2. ***Complexity*****:** OTEC plants must be located where a difference of about 20°C occurs year round. Ocean depths must be available fairly close to shore-based facilities for economic operation. Floating plant ships could provide more flexibility.

3. ***Acceptability*****:** For the large-scale production of electricity and other products, OTEC plants are poorly acceptable due to their high costs.

4. ***Ecosystem damage*****:** It is obvious by setting OTEC plants.

5. ***Lower efficiency*****:** A higher temperature difference between ocean surface warm water and cold deep ocean water is required for highly efficient operation of plant.

Economic and other benefits are the value of OTEC plants.

1. It is a clean, renewable natural resource available in plenty.
2. It has no environmental problems and greenhouse effects.
3. It is a source of base load electricity and fuels such as hydrogen, methanol, and ammonia.
4. It provides freshwater for drinking, agriculture, and industry.
5. It encourages chilled agriculture and aquaculture.
6. Self-sufficiency, no environmental effects, and improved sanitation and nutrition are the added benefits for island.

Worldwide OTEC Power plants

Table 1. Important worldwide installed or planned OTEC power plants (Ravindran 2000; Wikipedia contributors 2015a).

Location	Nominal or nameplate power output	Description
Hawaii	50 kW	One of the oldest plant, 1979, closed cycle, Lockheed Missile and Space Co.
Japan/Nauru	120 kW	Installed in 1982 by Tokyo Electric Power Services Company
Hawaii	1 MW	A land-based plant, open cycle, operating between 1993–1998 by LLC and NELHA
Japan/Okinawa	50 kW	A land-based plant using for power generation and research on other applications of OTEC, installed in 2013 by Xenesys, IHI and Yokogawa
Hawaii	10 MW	Working with the U.S. Navy and the Department of Energy, Lockheed Martin has invested $15 million over the past three years toward the technology need for and the design of a 10 MW prototype plant to validating the technologies necessary for small- to large-scale (100 MW or greater) commercial sized OTEC power plants
India/Tuticorin south India	1 MW	A floating closed cycle plant was attempted by the National Institute of Ocean Technology, India. Difficulties in connecting the 1 km cold water pipe due to lack of marine infrastructure led to closure of the project
Southern China	10 MW	The 10 MW prototype offshore plant will be the largest planned OTEC project until 2017. Like the Hawaii project, which was also to be a 10 MW facility, the China OTEC plant is designed to pave the way for higher capacity plants ranging from 10 to 100 MW
Martinique/Bellefontaine	10 MW	Floating platform, planned to operate from 2016, DCNS France

Problems associated with ocean thermal energy conversion

1. **High capital and operational costs:** Building and maintaining OTEC systems can be expensive. The need for specialized infrastructure, materials, and equipment adds to the initial investment and ongoing operational costs.
2. **Limited geographic applicability:** OTEC is most suitable in regions where there is a significant temperature difference between surface and deep ocean waters, typically found in tropical and subtropical regions. This limits its widespread global applicability.
3. **Environmental impact:** While OTEC does not produce direct greenhouse gas emissions during operation, its installation and operation can have environmental impacts. For example, the cold water discharged from OTEC plants can lead to changes in local marine ecosystems and affect marine life.
4. **Technical challenges:** OTEC systems require complex engineering solutions to withstand harsh marine conditions, corrosion, and biofouling. Additionally, transferring cold seawater from the depths to the surface may require energy-intensive pumps.
5. **Low efficiency:** Current OTEC systems have relatively low energy conversion efficiency, which means they produce less electricity compared to other renewable energy sources like solar or wind power.
6. **Intermittent power generation**: OTEC is dependent on temperature differences between the surface and deep seawater, which can vary due to weather patterns and ocean currents. This can result in intermittent power generation, making it challenging to provide consistent electricity supply.
7. **Distance from shore:** OTEC facilities are typically located offshore, which can lead to transmission and distribution losses when transporting electricity to populated areas.
8. **Sensitive to weather conditions:** Storms, hurricanes, and rough seas can damage OTEC infrastructure, leading to interruptions in power generation and potentially costly repairs.
9. **Competition with other renewable energy sources:** OTEC faces competition from well-established and cost-effective renewable energy sources like solar, wind, and geothermal power.
10. **Limited scalability:** As of my last update in September 2021, OTEC technology was still in the early stages of development, and large-scale commercial deployment had not been realized. The technology's scalability and potential to meet significant portions of global energy demand remain uncertain.