Module-5

Sea Wave Energy: Introduction, Motion in the sea Waves, Power Associated with Sea Waves, Wave Energy Availability, Devices for Harnessing Wave Energy, Advantages and Disadvantages of Wave Power.
Ocean Thermal Energy: Introduction, Principles of Ocean Thermal Energy Conversion (OTEC), Ocean Thermal Energy Conversion plants, Basic Rankine Cycle and its Working, Closed Cycle, Open Cycle and Hybrid Cycle, Carnot Cycle, Application of OTEC in Addition to Produce Electricity, Advantages, Disadvantages and Benefits of OTEC.

The material from this is prepared only for educational use from various text books and material from internet
Questions from VTU model papers and few important questions

1. Explain the principle and working of wave energy. What are the limitations of wave energy
2. Discuss the merits and demerits of sea wave power extraction
3. What is sea wave energy. explain in brief the challenges in harnessing the sea wave power
4. What are the various devices for harnessing sea wave energy. explain in brief
5. Explain the working of salters duck, with the help of neat sketch
6. With a neat sketch explain the oscillating water column device for harnessing wave energy
7. What is the principle of working of OTEC?
8. Discuss various applications of OTEC including electricity generation
9. Briefly explain the problems associated with OTEC and OTEC power stations in the world.
10. Described the Closed cycle OTEC System with the help of diagram
11. What are the advantages, disadvantages, and benefits of OTEC
12. What are the environmental impacts of OTEC plant
13. What are the relative advantages and imitations of OTEC plant
14. Explain the basic Rankine cycle and its working
15. Explain the open cycle and closed cycle OTEC techniques

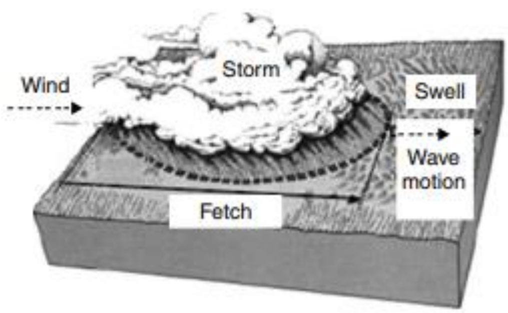
Sea Wave Energy

Introduction: Waves get their energy from the solar energy through the wind. Wave energy will never be depleted as long as the sun shines. Energy intensity may, however, have variation but it is available 24 hrs a day in the entire year. They are caused by the wind blowing over the surface of the ocean with enough consistency and force in many areas of the world to provide continuous waves along the shore line. It contains tremendous energy potential and wave power devices extract energy from either the surface motion of ocean waves or from pressure fluctuations below the surface.
The movement of the ocean water and the changing water wave heights and speed of the swells are the main sources of wave energy. Kinetic energy in the wave motion is tremendous that can be extracted by the wave power devices from either the surface motion of ocean waves or from pressure fluctuations below the ocean surface.

MOTION IN THE SEA WAVES

When the wind blows across smooth water surface, air particles from the wind grab the water molecules they touch. Stretching of the water surface by the force or friction between the air and the water creates capillary waves (small wave ripples). Surface tension acts on these ripples to restore the smooth surface, and thereby, waves are formed.

The combination of forces due to the gravity, sea surface tension, and wind intensity are the main factors of origin of sea waves as shown in Figure 5.1, which illustrates the formation of sea waves by a storm. Wave size is determined by wind speed and fetches (defined as the distance over which the wind excites the waves) and by the depth and topography of these abed (which can focus or disperse the energy of the waves). Sea waves have a regular shape at far distance from the fetch and this phenomenon is called swell. Wave formation makes the water surface further rough and the wind continuously grips the roughened water surface, and thus, waves are intensified.
A wave is a forward motion of energy and not the water in deep sea. In true sense, the seawater does not move forward with a wave. Waves are characterized by the following parameters, as shown in Figure 5.2.



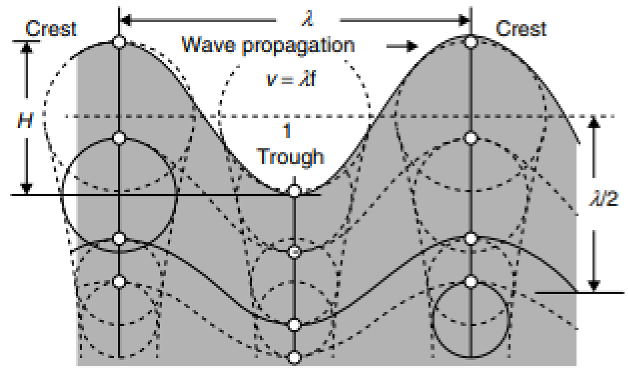


Figure 5.1 Sea wave formation by storm

Figure 5.2 Sea wave propagation

1. Crest: The peak point (the maximum height) on the wave is called the crest.
2. Trough: The valley point (the lowest point) on the wave is called the trough.
3. Wave height (H): Wave height is a vertical distance between the wave crest and the next trough (m).
4. Amplitude (a): It is defined as H/2 (m).
5. Wave length (l): It is the horizontal distance either between the two successive crests or troughs of the ocean waves (m).
6. Wave propagation velocity (v): The motion of seawater in a direction (m/s).
7. Wave period (T): It measures the size of the wave in time(s). It is the time required for two successive crests or two successive troughs to pass a point in space.
8. Frequency (f): The number of peaks (or troughs) that pass a fixed point per second is defined as the frequency of wave and is given by f = 1/T (cycle/s).

POWER ASSOCIATED WITH SEA WAVES

It has been concluded by researchers through linear wave motion theory that the kinetic and potential energy (E) of a wave per meter of crest and unit of surface can be approximated as

$$E = \rho g a^2/2 \quad \text{-------------(5.1)}$$

where r = density of water; g = gravitational acceleration; and a = amplitude of the wave (approximately equals to half its wave height H).
The power that a meter of crest holds can be obtained by multiplying the amount of energy transported by the group velocity.
In deep water, dispersion relation (k) is given as- $k = \omega^2/g,$ ---------(5.2)
Further, group velocity- $(V_g) = \omega/2k = g/2\omega$ ---------(5.3)
The total power (P) is obtained as $P = EV_g = [\rho g\, a^2/2](g/2\omega) = \rho g^2 a^2/4\omega$ ----------(5.4)
Further, wave period $(T) = 2\pi/\omega$ or $\omega = 2\pi/T$ and $a = H/2$
Therefore, $P = \rho g^2 a^2/4\omega = \rho g^2 H^2 T/32\pi$ ----------(5.5)

For irregular waves of height H (m) and period T(s), an equation for power per unit of wavefront can be derived as $P_{irregular} = 0.4$ (kW/m) of wavefront --------(5.6)
From the above-mentioned equations, it is seen that the wave power is directly proportional to the square of wave height.

WAVE ENERGY AVAILABILITY

The density of water is about 800 times higher than air, and therefore, the energy density of ocean waves are significantly several times more than air. The amount of energy available in ocean waves is tremendously high, and hence, it is considered as a renewable, zero emission source of power. Estimates of the global ocean wave energy are more than 2 TW (which means 17,500 TWh/year) according to the World Energy Council.

It has been reported that the total available US wave energy resource is 23 GW, which is more than twice as much as Japan, and nearly five times as much as Great Britain. The West Coast of US is the most promising area with wave energy densities in the range of 25–40 kW/m.
The ocean wave along the western coast of Europe is characterized by particularly high energy. It has over half the wave energy potential of Europe and has power up to extent of 75 kW/m off the coastal area of Ireland and Scotland.
Wave power is distinct from the diurnal flux of tidal power and the steady gyre of ocean currents. This huge amount of renewable and environmentally acceptable wave energy, if extracted and utilized, has competitiveness with fossil and nuclear fuels. Generally, extreme latitudes and west coasts of continents are the best wave location.
Wave energy is converted into electricity by placing wave energy converter on the surface of the ocean. The electrical energy generated is the most often used in desalination plants, power supply to electrical consumers, and energizing water pumps.
They are mostly using the first generation oscillating water columns (OWS) converters. Other technologies such as the Japanese Pendulor and the Tapchan can also be fit in this category.
These ocean wave energy technologies rely on the up-and-down motion of waves to generate electricity.
The next generation of devices comprises new, modular floating devices, but these require further research and/or demonstration.
The coastal area of Maharashtra has an annual wave potential ranging between 4 kW/m and 8 kW/m wavefront, which is quite high as 12–20 kW/m during the monsoon. The Vengurla and Malvan rocks and Redi are on the top among the offshore locations. In the coastal location, however, Pawa and Ratnagiri top the list followed by Girye and Miyet point. Vizhinjam fishing harbour, Kerala, is the site of a unique demonstration plant that converts sea wave energy to electricity and is given to the local grid. This plant has oscillating water column (OWC) converter in 1990.

DEVICES FOR HARNESSING WAVE ENERGY

There are three basic technologies for converting wave energy to electricity. They are as follows:
1. Terminator devices: It is a wave energy device oriented perpendicular to the direction of the wave and has one stationary and one moving part. The moving part moves up and down like a car piston in response to ocean waves and pressurizes air or oil to drive a turbine. An oscillating water column (OWC) converter is an example of terminator device. These devices generally have power ratings of 500 kW to 2 MW, depending on the wave parameters and the device dimensions.

2. Attenuator devices: These devices are oriented parallel to the direction of the waves and are long multi-segment floating structures. It has a series of long cylindrical floating devices connected to each

other with hinges and anchored to the seabed. They ride the waves like a ship, extracting energy by using restraints at the bow of the device and along its length. The segments are connected to hydraulic pumps or other converters to generate power as the waves move across. Pelamis wave energy converter is one of the known examples of attenuator devices.

3. Point absorber: It is a floating structure with parts moving relative to each other owing to wave action but it has no orientation in any defined way towards the waves instead absorbs the wave energy coming from any direction. It utilizes the rise and fall of the wave height at a single point for energy conversion. The pressurized water creates up and down bobbin-type motion and drives a built-in turbine generator system to generate electricity. AquaBuOY WEC is an example of point absorber devices.

4. Overtopping devices: These devices have reservoirs like a dam that are filled by incoming waves, causing a slight build-up of water pressure. Gravity causes released water from reservoir to flow back into the ocean through turbine coupled to an electrical generator. Salter Duck WEC is the example of overtopping devices.

Oscillating Water Column Devices

An oscillating water column device (OWC device) is shown in Figure 5.3. It is a form of terminator in which water enters through a subsurface opening into a chamber, trapping air above. The wave action causes the captured water column to move up and down like a piston, forcing the air though an opening connected to a turbine to generate power.

It is a shoreline-based oscillating water column (OWC) build in UK. Further, it is installed at Islay. It is a concrete structure partially submerged in seawater and encloses a column of air on top of a column of water. The water columns in partially submerged chamber rise and fall, when sea waves impinge on the device. This wave action alternatively compresses and depressurizes the air column, which is allowed to flow to and from the atmosphere via a turbine. The energy can then be extracted from the system and used to generate electricity.

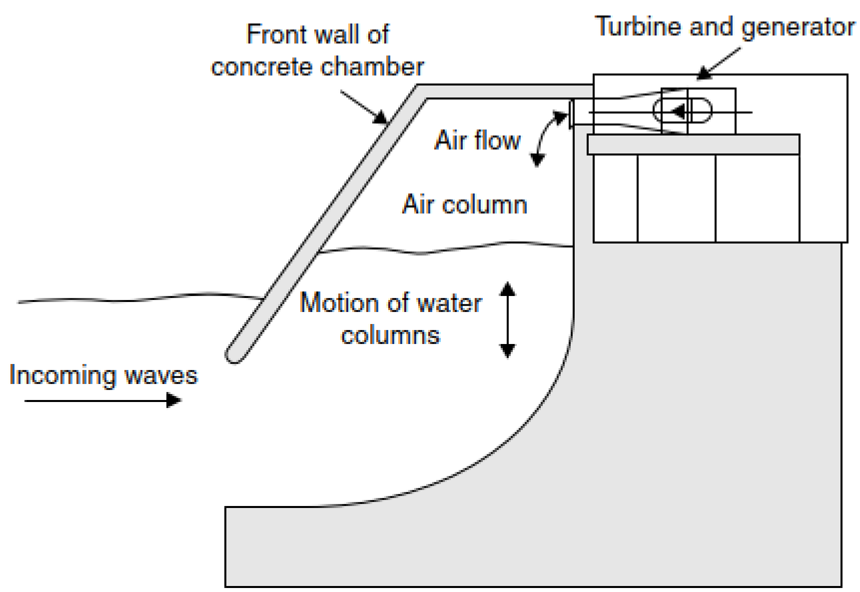


Figure 5.3 Schematic of an oscillating water column device

Pendulum System

The pendulum system is a shoreline device that consists of a parallelepiped concrete box, which is open to the sea at one end, as shown in Figure 5.4.

A pendulum flap is hinged over this opening, which swings back and forth by the actions of the waves. The back and forth motion of pendulum is then used to power a hydraulic pump and an electric generator.

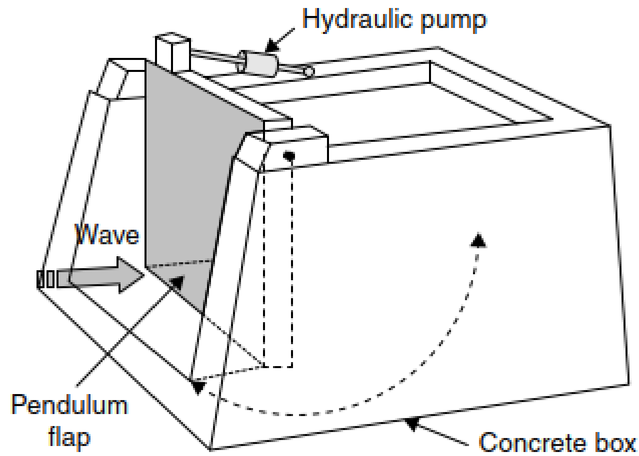


Figure 5.4 Pendulum devices

Salter's Duck System

Salter Duck WEC is the example of overtopping devices. It was invented in Scotland in 1970 to extract mechanical energy from the ocean waves. The schematic cross section of Salter Duck is given in Figure 5.5.

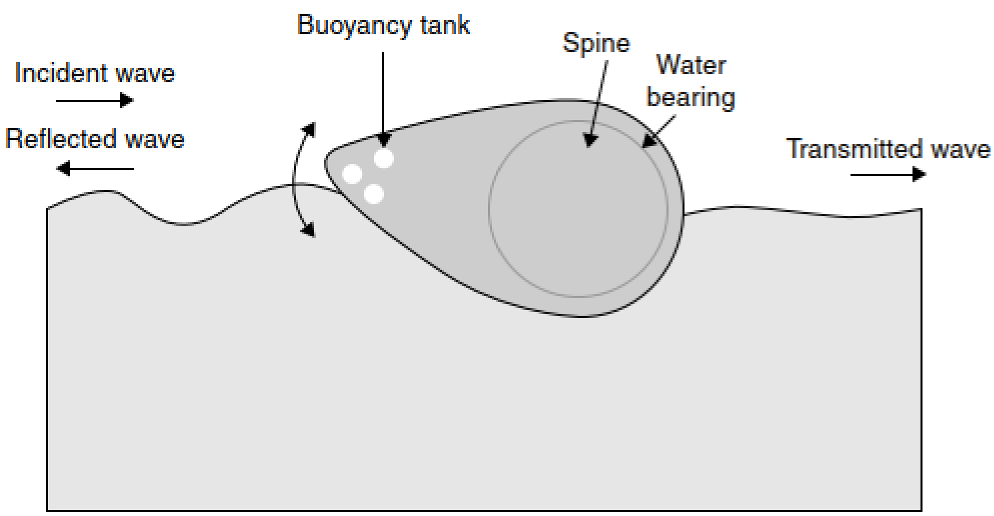


Figure 5.5 Salter duck

It is an egg-shaped device that moves with the motion of the waves. The shape of leading edge of the duck is in such a way that the approaching sea wave pressure is exerted on the duck. It forces the duck to rotate about a central axis and the tip of the cam bobs up and down in the water. As the Salter Duck moves (or bobs or rocks) up and down on the sea waves, pendulum connected to electrical generator swings forward and backward to generate electricity. Two sets of cables are attached to the device, one to a pendulum inside the device and the other to a fixed arm outside the device. The cables attached to the internal pendulum contain hydraulics that pumps as the device moves back and forth with the waves. This movement of the pressurized oil pumped into hydraulic machine that drives electric generators.

Bristol Cylinder

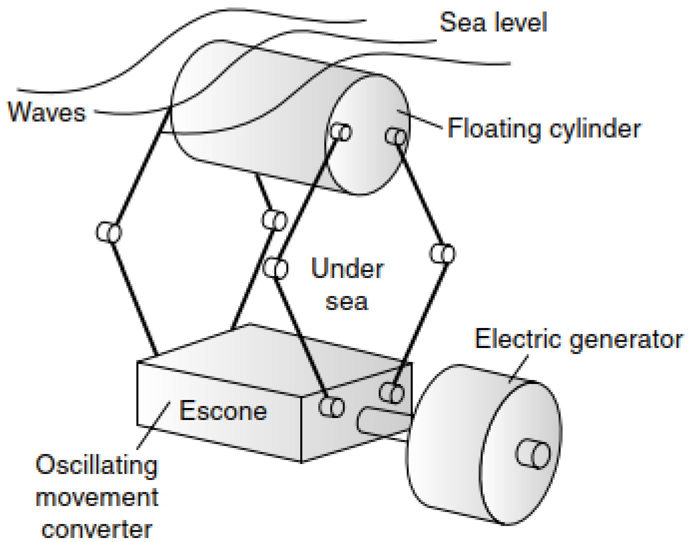


Figure 5.6 Bristol cylinder devices

The Bristol cylinder operates under the sea level, as shown in Figure 5.6. It consists of a floating cylinder that collected the wave's movement. The cylinder is mechanically connected to the energy unit by flexible joints and rods. The rods are moving slowly with cylinder and the reciprocating motion is transferred to the axels in converter unit.

When transferring converter movements with mechanical arms and rotation to the generator, the efficiency should be kept as high as possible.

ADVANTAGES AND DISADVANTAGES OF WAVE POWER

Advantages

1. Sea waves have high energy densities and provide a consistent stream of electricity generation capacity.
2. Wave energy is clean source of renewable energy with limited negative environmental impacts.
3. It has no greenhouse gas emissions or water pollutants.
4. Operating cost is low and operating efficiency is optimal.
5. Damage to ocean shoreline is reduced.

Disadvantages

1. High construction costs.
2. Marine life is disrupted and displaced.
3. Damage to the devices from strong storms and corrosion create problems.
4. Wave energy devices could have an effect on marine and recreation environment.

Ocean Thermal Energy:

INTRODUCTION

Low-temperature heat obtained from renewable energy resources, such as solar thermal, geothermal, ocean thermal, etc. is presently converted into electricity and utilized for direct heating applications. About 70% of earth's surface is covered by ocean which is continuously heated by solar heat. 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.

However, significant amount of electric power can be generated in the location where a temperature difference of 20°C and above exists between warm surface water and cold deep water.

In many regions, ocean surface water is generally maintained at 25°C or above and more than 1,000 metres below the surface is generally at about 5°C. Since average temperature in Baltic Sea is about 10°C, setting up of OTEC electrical power plant is not profitable.

Therefore, OTEC is an energy technology that converts solar radiation to electric power through heat of ocean water. These systems use ocean's natural thermal gradient. 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.

The cold deep sea water used in the OTEC system is also rich in nutrients, and it can be used to cultivate plant and marine organism near the shore or on land.

PRINCIPLE OF OCEAN THERMAL ENERGY CONVERSION

The basic principle of ocean thermal energy conversion (OTEC) is explained as follows:

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.

If ocean surface water is high, enough propane or similar material is used as working fluid; otherwise, for low-temperature surface water, fluid such as ammonia with low boiling point is used.

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. Some fractions of electrical power generated by OTEC plants are used for operating and controlling equipments involved in power plants, and high electrical power is used for feeding to several other energy consumers.

OCEAN THERMAL ENERGY CONVERSION PLANTS

There are two different kinds of OTEC power plants, namely land-based power plant and floating power plant.

1 Land-based Power Plant

The land-based power plant will consist of a building as shown in Figure 5.7. It is constructed on shore and accommodates all parts of OTEC plants. It requires laying down long pipes from plant site on shore to two extreme points of necessary temperature gradient.

One pipe is used to collect warm ocean surface water through screened enclosure near the shore. Another long pipe lay down on the slope deep into the ocean to collect cold water.

A third pipe is used as outlet to discharge used water again in ocean via marine culture ponds deep down the ocean. Cost of pipe installation and maintenance is very expensive, and land based plant is also very expensive. Since large electricity is used to pump water through long pipes, the net electricity reduces considerably.

Land-based OTEC plant has the advantage of savings on electrical transmission line and connectivity to electrical power grid.

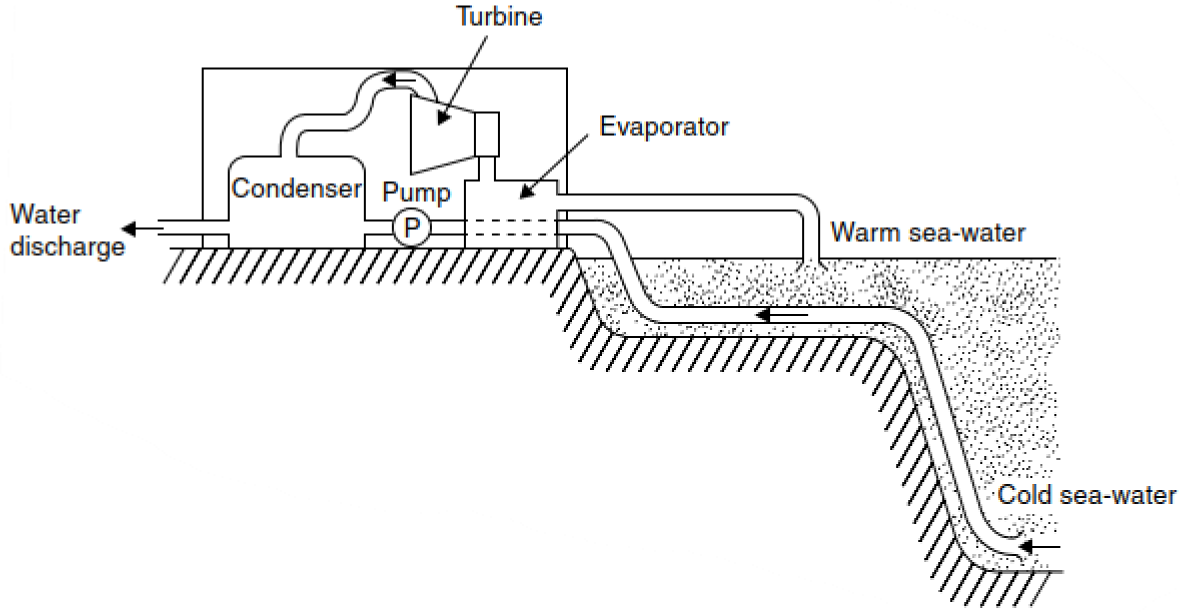


Figure 5.7 Land-based OTEC power plant

2 Floating Power Plant

Floating power plant is built on a ship platform exactly where required temperature gradient sufficient for OTEC plant is available. The working principle of ocean thermal energy conversion (OTEC) is same as that of land-based power plant. Undoubtedly, the cost savings exist on piping system, but long transmission line is required to transmit electrical power from plant to sea shore.

Owing to high installation cost of long underwater power cables and its inefficiency and many other associated problems, floating OTEC plants are considered for the production of fuels, such as hydrogen, on the platform itself by the electrolysis of water.

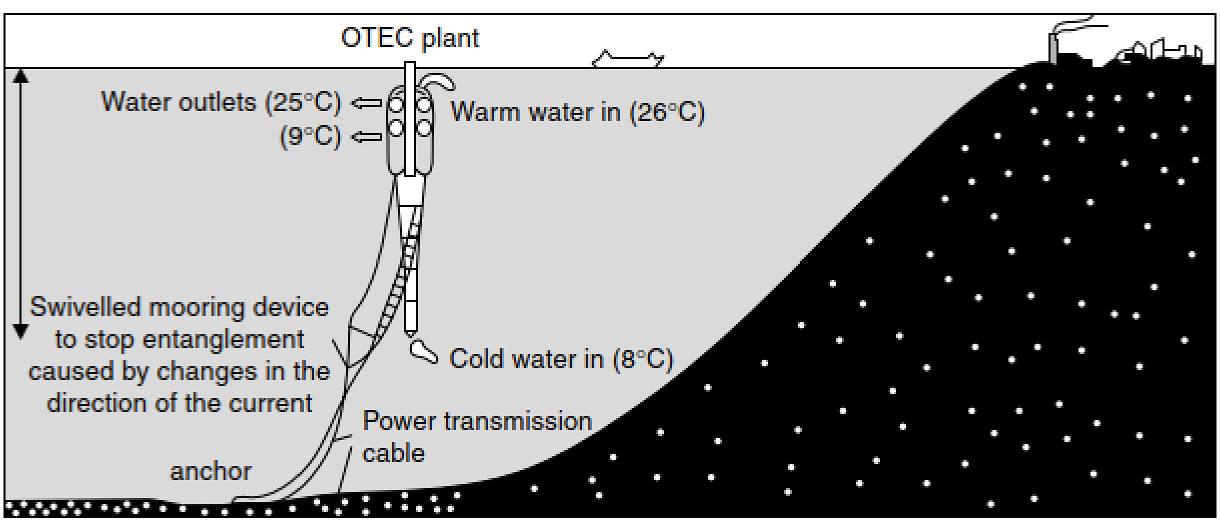


Figure 5.8 Floating OTEC power plant

Cold water pipe is the largest single item in the land-based plant design, as the slopes are seldom larger than 15° or more. If 1,000-metres-long vertical pipe with 10 to 15 m diameter used in floating plant, the length of land-based plant considering slope will be about three times.

BASIC RANKINE CYCLE AND ITS WORKING

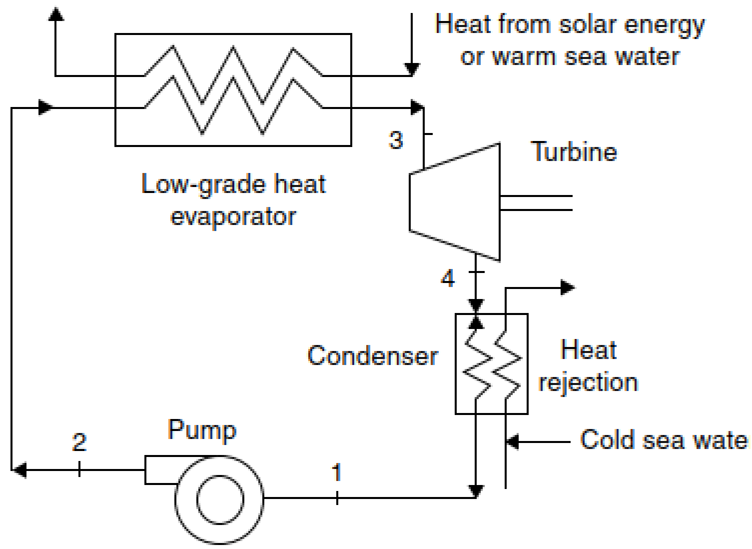


Figure 5.9 OTEC Rankine cycle

The basic Rankine cycle shown in Figure 5.9 consists of the following:

1. An evaporator
2. A turbine expander
3. A condenser
4. A pump
5. A working fluid

In open-cycle OTEC, warm sea water is used as working fluid, whereas in closed-cycle type, low-boiling point ammonia or propane is used.

Warm ocean surface water flows into the evaporator which is the high-temperature heat source. A fluid pump is utilized to force the fluid in a heat evaporator where liquid fluid vapourizes. Then, the vapour of boiling fluid enters the turbine expander coupled with an electrical generator to generate electrical power. The vapour released from the turbine enters into condenser where it condenses. The cold deep sea water is pumped through the condenser for heat rejection from vapour fluid and condenses it as liquid fluid. The liquid fluid is again pumped through evaporator and cycle repeats.

As temperature difference between high- and low-temperature ends is large enough, the cycle will continue to operate and generate power.

CLOSED CYCLE, OPEN CYCLE, AND HYBRID CYCLE

There are three types of OTEC cycle designs, namely open cycle, closed cycle, and hybrid cycle.

1. In an open cycle, warm sea water is pumped into a flash evaporator as working fluid where it boils at low pressure and converts into steam. This steam expands through low-pressure turbine which drives an electrical generator and generates electricity. The steam released from turbine condensed in a condenser by deep sea cold water as non-saline water. When non-condensable gases are separated and exhausted, the non-saline water is either pumped in marine culture ponds for freshwater applications or finally discharged in sea surface water.

2. In closed cycle, organic fluid flows in a separate closed-cycle loop called organic Rankine cycle. Warm sea surface water pumped through another pipe vapourizes working fluid in heat exchangers to drive turbine generator, The fluid vapour condenses into liquid form by deep sea water pumped in condenser by a separate pumping system, The process of pumping liquid fluid in an evaporator cycle is repeated.

3. A hybrid cycle is a combination of both closed and open cycle.

1 Open-cycle OTEC

An open-cycle OTEC uses the warm ocean surface water as working fluid. It is a non-toxic and environment friendly fluid. The major components of this system are shown in Figure 5.6. It consists of evaporator, low-pressure turbine coupled with electrical generator, condenser, marine culture ponds, non-condensable gas exhaust, and pumps. Evaporator used in an open-cycle system is a flash evaporator in which warm sea water instantly boils or flash in the chamber that has reduced pressure than atmosphere or vacuum. It results in reduced vapourization pressure of warm sea water. A large turbine is required to accommodate large volumetric flow rates of low-pressure steam, which is needed to generate electrical power, and is used with other plant components in a similar manner. During vapourization process in an evaporator, oxygen, nitrogen, and carbon dioxide dissolved in sea water are separated and are non-condensable. They are exhausted by non-condensable gas exhaust system. Condenser is used to condense vapour or steam released from steam turbine is condensed by cold deep sea water and returned back to sea.

If a surface condenser is used, condensed steam (desalinated water) remains separated from cold sea water and is pumped into marine culture ponds. To avoid leakage of air in atmosphere and to prevent abnormal operation of plants, perfect sealing of all components and piping systems is essential. The working principles of open-cycle OTEC plants are explained as follows with the help of Figure 5.10.

1. 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.
2. 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.
3. 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.
4. The condensed non-saline water is discharged either directly in deep sea cold water or through the marine culture pond.
5. The non-condensable gases are compressed to pressure and exhausted simultaneously.
6. The warm ocean surface water is continuously pumped into evaporator and cycle repeats.

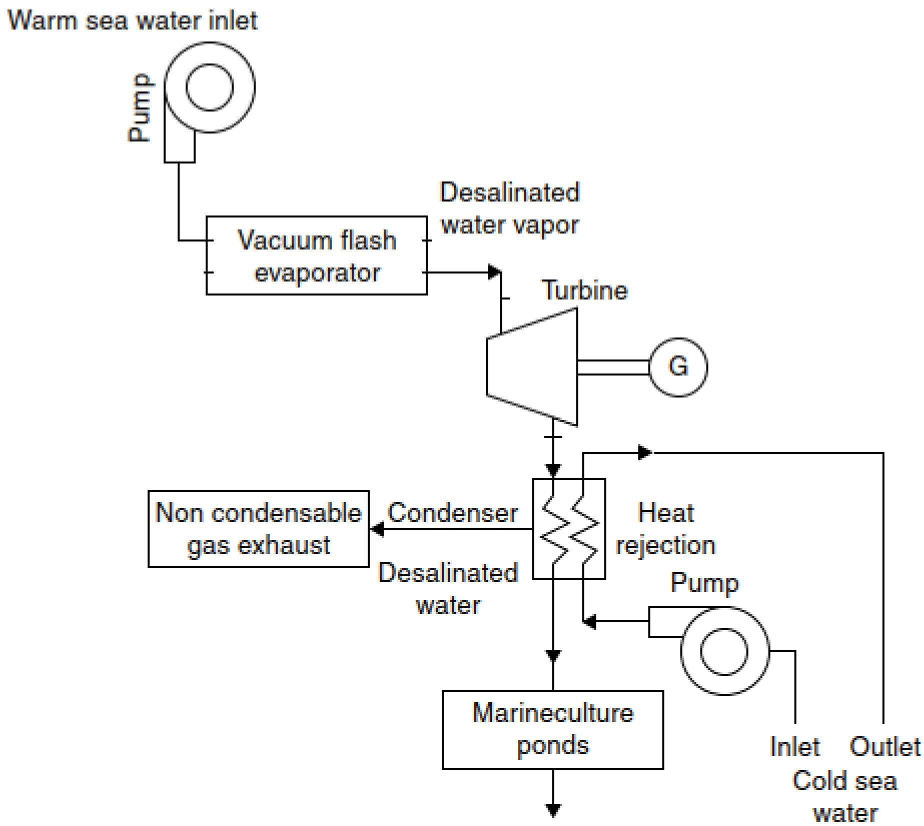


Figure 5.10 Open-cycle OTEC

2 Closed-cycle OTEC

The schematic of closed-cycle OTEC is shown in Figure 5.11. It has different arrangement when compared to open-cycle OTEC. Organic fluid with low boiling point is used as working fluid. Ammonia liquid is the most widely used working fluid. Working fluid flows in a closed loop and perfectly sealed piping system. Working fluid circulates around the loop continuously. Warm ocean surface water flows through completely separate piping system and discharges in upper surface of ocean. Warm surface sea water and working fluid piping are placed very closely to each other in a heat exchanger to transfer warm sea water heat into working fluid. The cold deep sea water piping system is in contact with working fluid piping system in a condenser where working fluid condenses to its liquid state. Other components of both open- and closed-cycle OTECs are similar. Working principles of closed-cycle OTEC are as follows:

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

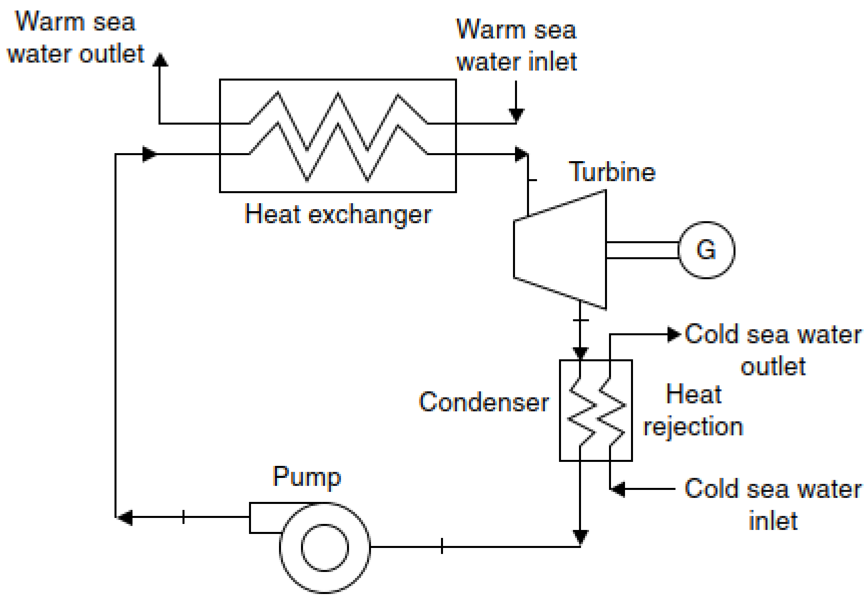


Figure 5.11 Closed-cycle OTEC plant

3 OTEC Hybrid Cycle

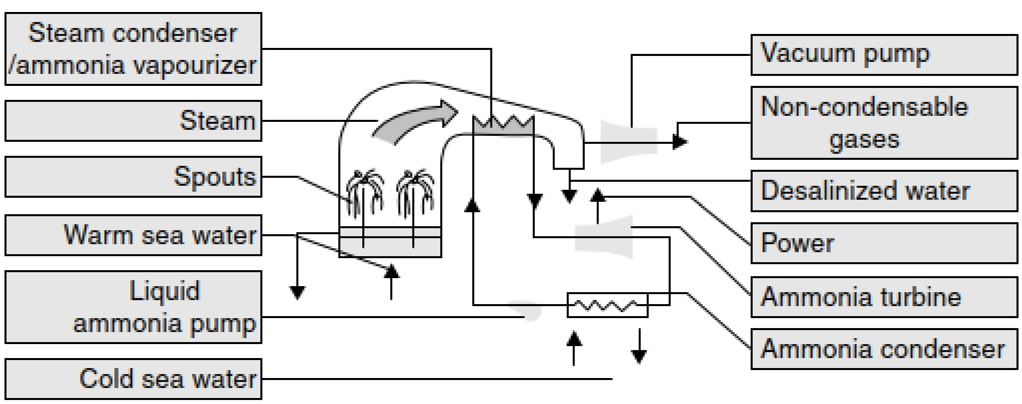


Figure 5.12 OTEC hybrid cycle

As shown in Figure 5.12, a hybrid cycle combines the features of both closed-cycle and open-cycle systems. Warm sea water is pumped into a vacuum chamber where it is used to flash and produces steam. Working fluid in another closed cycle loop is evaporated and vapourized by steam in vacuum chamber. The fluid vapour rotates the turbine and drive an electric generator to produce electricity.

CARNOT CYCLE

The Carnot cycle is the most efficient thermodynamical cycle by exploiting the warm sea surface water and cold deep sea water.

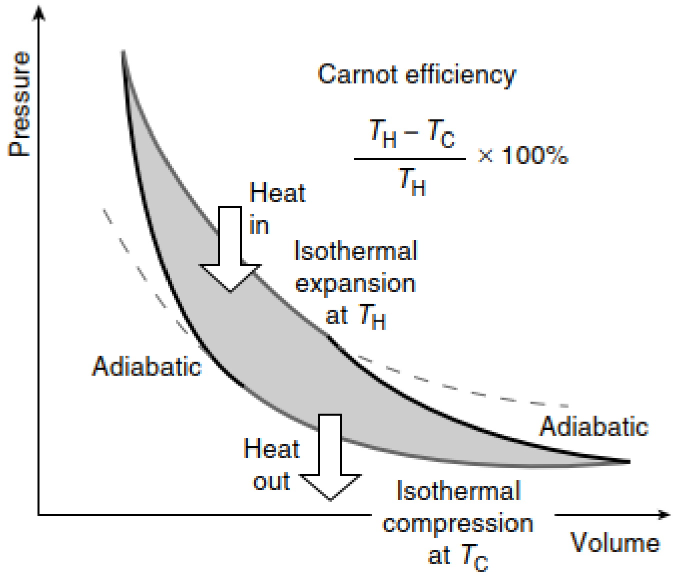


Figure 5.13 Carnot efficiency P–V diagram

Let W be the work done by the system (energy exiting the system as work), QH be the heat put into the system (heat energy entering the system),
TC be the absolute temperature of the sea surface and
TH be the absolute temperature of the deep sea water hot reservoir.
Carnot efficiency (h) is given by the following equation: $\eta = W/Q_H = 1 - T_C/T_H$

APPLICATION OF OTEC IN ADDITION TO PRODUCE ELECTRICITY

OTEC schematic diagram and applications are shown in Figure 5.14. Ocean thermal converting plants provide several products for use by mankind. These are explained as follows:

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. Chilled soil agriculture: Chilled soil agriculture is another application of OTEC plants. Cold deep sea water flowing through underground pipes chills the surrounding soil. The temperature difference is maintained between plant roots in the cool soil and plant leaves in the warm air, and thus, the tree and plants grows. The amount of food that can be produced in this way is very large, larger in market value than the electric power produced by the plant.

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

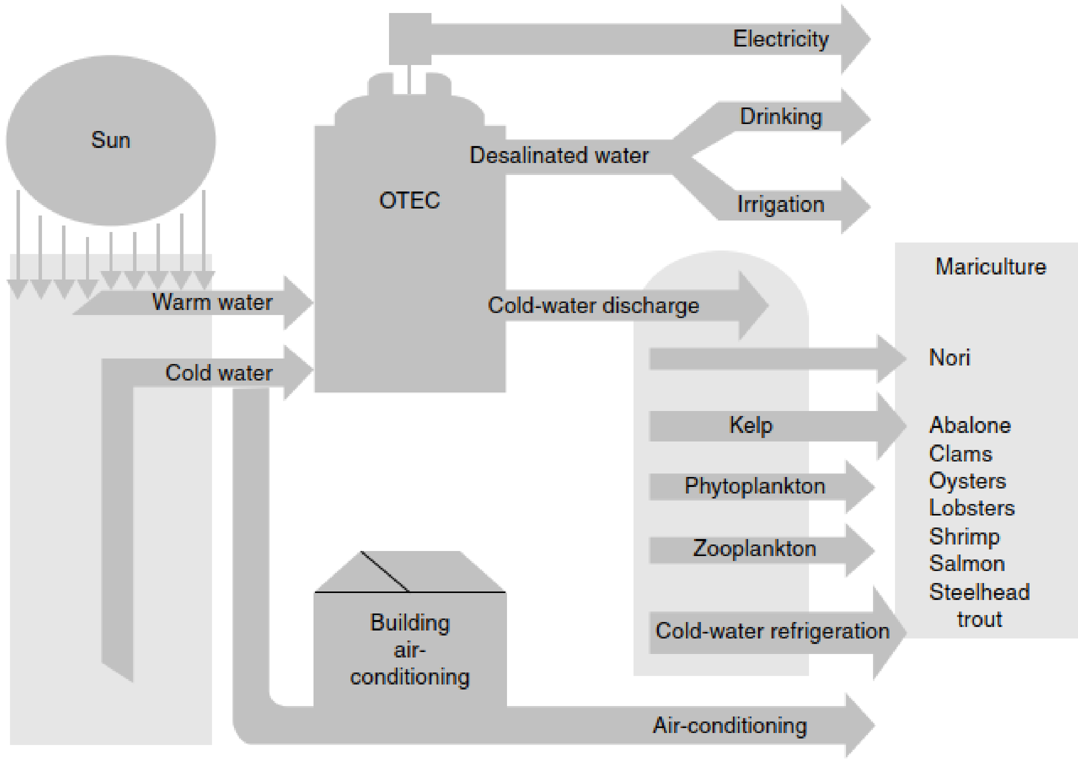


Figure 5.14 OTEC plant and applications

ADVANTAGES, DISADVANTAGES AND BENEFITS OF OTEC

1 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.

2 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.

3 Benefits as a Measure of the Value of OTEC

Economic and other benefits are the value of OTEC plants. These include the following:

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.