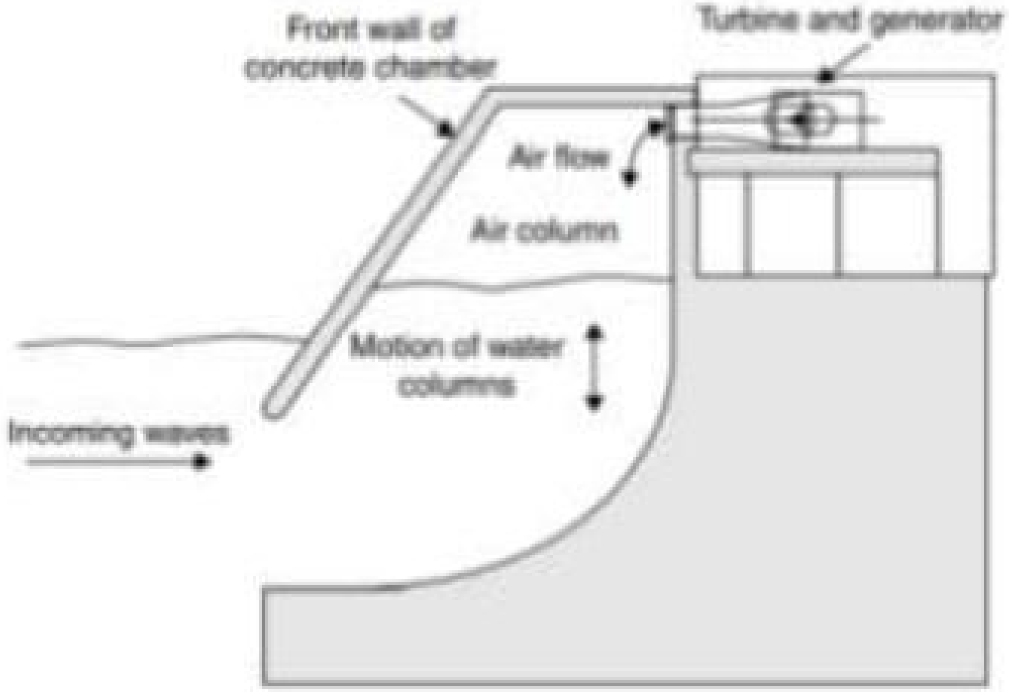
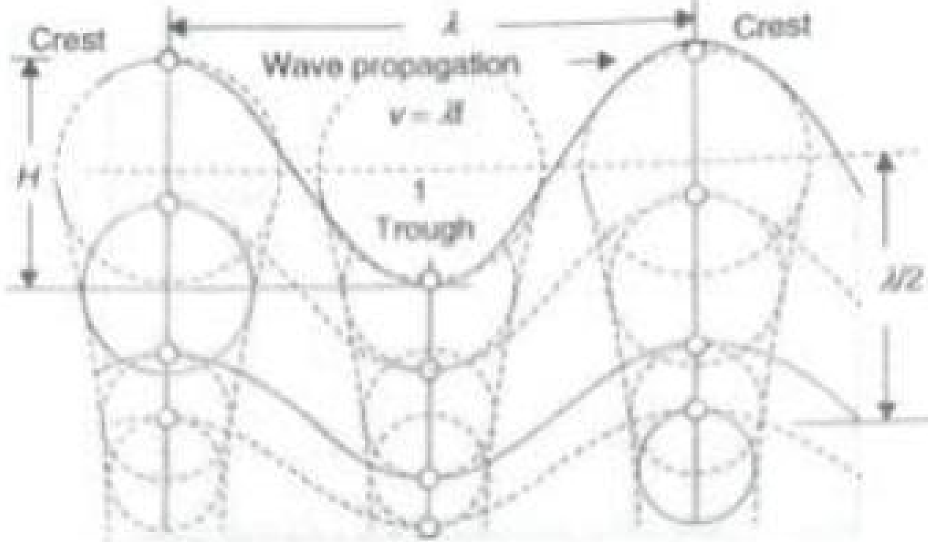
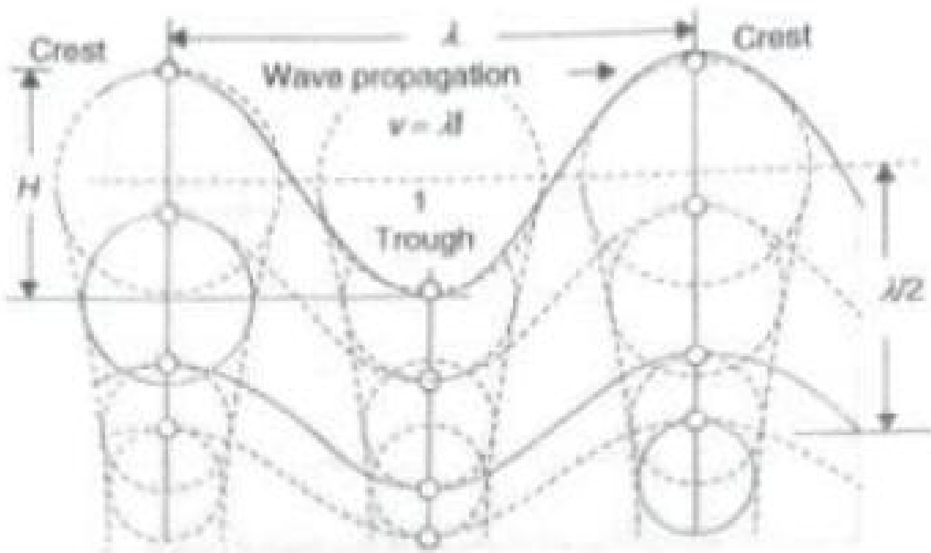
b) Oscillating Water Column Devices

An oscillating water column device (OWC device) is shown in Figure 12.5. 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. Wells' turbines as shown in Figure 12.6 are used to extract energy from the reversing air flow. It has the property of rotating in the same direction regardless of the direction to the airflow.


Front wall of
concrete chamber
Turbine and generator
Air flow
Air column
Motion of water
columns
Incoming waves

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* (λ): 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).

5.4.2 The Closed or Anderson, OTEC Cycle

A schematic of a closed-cycle OTEC power plant is shown in Fig. Heat exchanger known as evaporators and condensers are a key ingredient, since extensive areas of material are needed to transfer significant amounts of low quality heat of the low temperature differences being exploited.

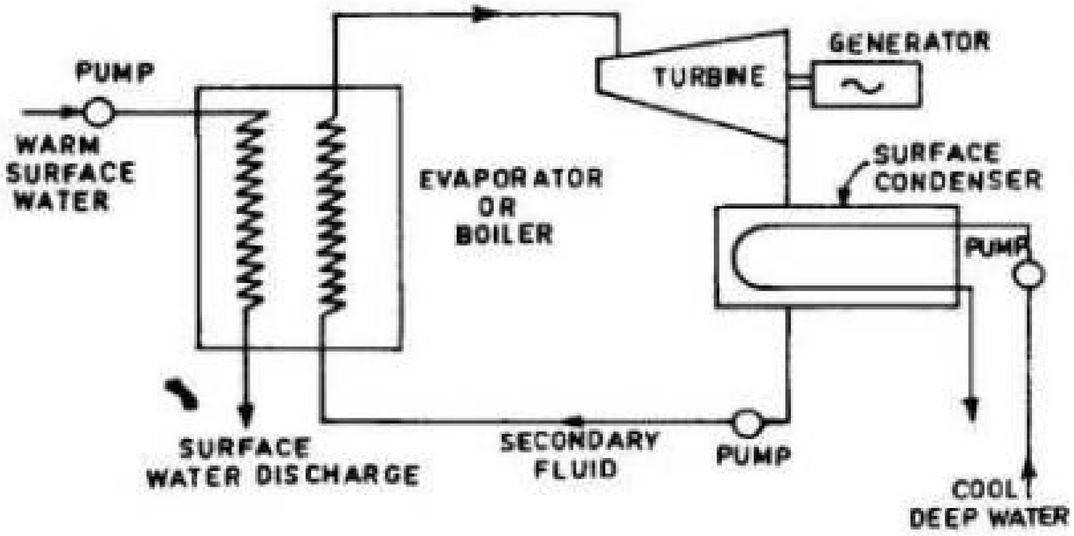
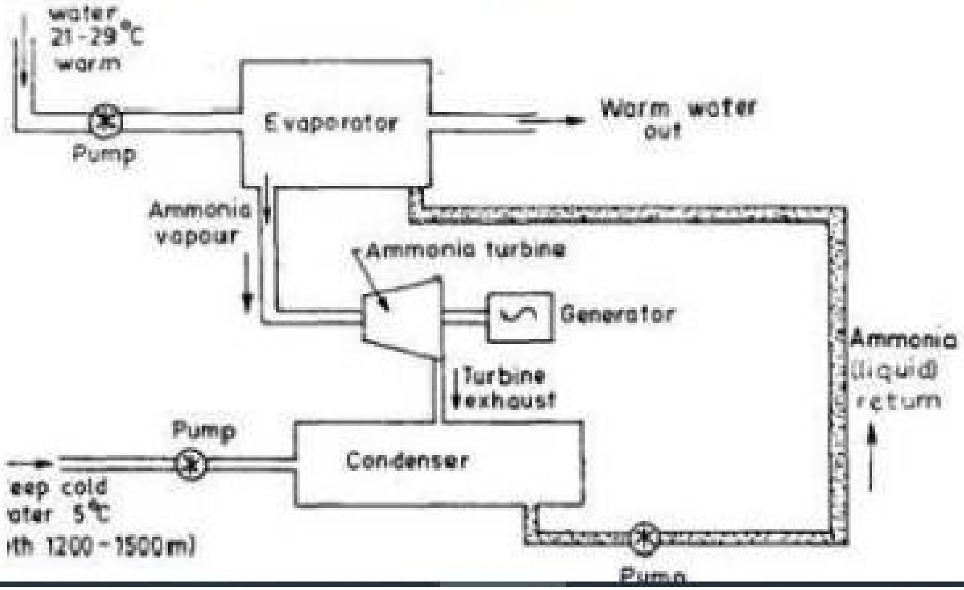


Fig. Schematic of an OTEC closed cycle system.

In other words, large volumes of water must be circulated through the OTEC power plant, requiring commensurately large heat exchangers. The actual components employed in an OTEC closed cycle system would appear more like the hardware illustrated in **Fig.2another** closed cycle schematic. This cycle requires a separate working fluid that receives and rejects heat to the source and sinkvia heat exchangers (boiler or evaporator and surface condenser). The working fluid may be ammonia, propane, or a Freon.

The operatingof such fluids at the boiler and condenser temperatures are much higher than those of water, being roughly10 kg/cm2 (10 bar) at the boiler, and their specific volumes are much lower, being comparable to those of steam in conventional power plants.

Such pressures and specific volumes result in turbines that are much smaller and hence less costly than those that use the low pressure steam of the open cycle. The closed cycle also avoids the problems of the evaporator. It however, requires the use of very large heat exchangers (boiler and condenser) because, for an efficiency of about 2 percent, the amounts of heat added and rejected are about 50 times the output of the plant. In addition, the temperature differences in the boiler and condenser must be kept as low as possible to allow for the maximum possible temperature difference across the turbine, which also contributes to the large surfaces of these units.



The closed cycle approach was first proposed by Barjot in 1926, but the most recent design was by Anderson and Anderson *in* the 1960s. The closed cycle is sometimes referred to as the Anderson Cycle. In the cycle propane was chosen as the working fluid. The temperature difference between warm surface and cool surface was 20°C. The c surface was at about 600 m deep. Propane is vaporized in the boilei evaporator at about 10 kg/cm2 (10 bar) or more and exhausted in 1 condenser at about 5 bar. Instead of usual heavier and more expensive shell and tube h exchangers, the Anderson OTEC system employs thin plate type h exchangers, which minimizes the mass and the amount of material a

hence cost. The heat exchangers are placed at depths where the sta pressure of the water in either heat exchanger roughly equals i pressure of the working fluid, this helps in reducing the thickness of plates. A fundamental requirement in closed cycle systems is to trans. heat efficiently across the heat exchanger surfaces constituting t evaporators and condensers, so as to achieve a high value of overall h transfer coefficient (U) measured in watts per kelvin per square meter or W/°K/m2. For the evaporation, this overall heat transfer coefficient is a measure of how effectively heat is transferred sequentially from s water through the heat exchanger materially (a metallic alloy) a hence to the working fluid *(e.g.,* ammonia). For the condenser, an over U characterized the reverse heat transfer process.

In an ocean environment, it is likely that a layer of slime known as “bio fouling” will *eventually* accumulate on the water side of the he exchangers. Such slime is first comprised or micro-organisms, at which stage, the bio fouling is called “micro fouling”. Subsequently, if the slime is not removed, additional bio-fouling in the form of micro-organism will become attached, augmenting the slime layer. The occurrence micro-fouling seems to be a pre-requisite for the attachment of macro organisms. A film of corrosion and possibly of calcareous *(e.g.* minerals deposits can also accumulate on the water side (and conceivably through leakage—even on the working fluid side of the heat trans surfaces). The total formulation of bio-fouling, corrosion, and so on, referred to a “fouling” (or scaling) and will tend to inhibit heat trans through it. The “fouling factor” is a measure of the thermal resistance‘R_f’of a fouling film. This thermal resistance is the reciprocal of t corresponding heat transfer coefficient *‘h_f’of* the fouling film.

To maintain viable OTEC heat exchangers, provisions must be made to inhibit the formation of fouling layers and to remove any significant fouling that forms. Removal can be accomplished by periodically cleaning ti heat exchanger surfaces through mechanical, chemical or other means.

Although both closed-and open cycle turbine systems are being explored, it appears that closed-cycle systems offer the most promise for the near future. Each of the possible working fluids *(i.e.* ammon and propane) has advantages and disadvantages.

4 a) With a neat diagram, explain the different parts and working principle of biogas plant. [5 Marks]

It is a brick and cement structure having
the following five sections:
1. Mixing tank

2. Digester tank
3. Dome or gas holder
4. Inlet chamber
5. Outlet chamber

a) Mixing Tank It is the first part of biogas plants located above the ground level in which the water and cow dung are mixed together in equal proportions (the ratio of 1:1) to form the slurry that is fed into the inlet chamber.

b) Digester Tank It is a deep underground well-like structure and is divided into two chambers by a partition wall in between. It is the most important part of the cow dung biogas plants where all the important chemical processes or fermentation of cow dung and production of biogas takes place. The digester is also called as fermentation tank. It is cylindrical in shape and made up of bricks, sand, and cement built underground over the solid foundation. Two openings are provided on the opposite sides and at the specified height of digester for inflow of fresh cow dung slurry and outflow of used slurry as manure. The two long cement pipes are used as follows: 1. Inlet pipe opening into the inlet chamber for inputting the slurry in digester tank. 2. Outlet pipe opening into and outflow of used slurry as manure. The two long cement pipes are used as follows: 1. Inlet pipe opening into the inlet chamber for inputting the slurry in digester tank. 2. Outlet pipe opening into the overflow tank (outlet chamber) for the removal of spent slurry from the digester tank. A separator is also placed in the middle of digester tank to improve effective fermentations of feedstock.

c)Dome or Gas Holder

The hemispherical top portion of the digester is called dome. It has fixed height in which all the gas generated within the digester is collected. The gas collected in the dome exerts pressure on the slurry in the digester. The dome or gas holder is made either fixed dome or floating dome type. Cement and bricks are used in the construction of fixed dome, and it is constructed using approximately at the ground surface. Floating dome type is an inverted steel drum resting on the digester above the ground surface. The drum floats over the digester and moves up and down with biogas pressure.

d) Inlet Chamber

The cow dung slurry is supplied to the digester of the biogas plant via inlet chamber, which is made at the ground level so that the slurry can be poured easily. It has bell mouth sort of shape and is made up of bricks, cement, and sand. The outlet wall of the inlet chamber is made inclined so that the slurry easily flows into the digester.

e) Outlet Chamber

The digested slurry from the biogas plants is removed through the outlet chamber. The opening of the outlet chamber is also at the ground level. The slurry from the outlet chamber flows to the pit made especially for this purpose.

f) Gas Outlet Pipe and Valve The gas holder has an outlet at the top which could be connected to gas stoves for cooking or gas-lighting equipments or any other purpose. Flow of the gas from the dome via gas pipe can be controlled by valve. The gas taken from the pipe can be transferred to the point of use.

g) Foundation The foundation forms the base of the digester where the most important processes of biogas plant occur. It is made up of cement, concrete, and bricks strong enough so that it should be able to provide stable foundation for the digester walls and be able to sustain the full load of slurry filled in it. The foundation should be waterproof so that there is no percolation and leakage of water.

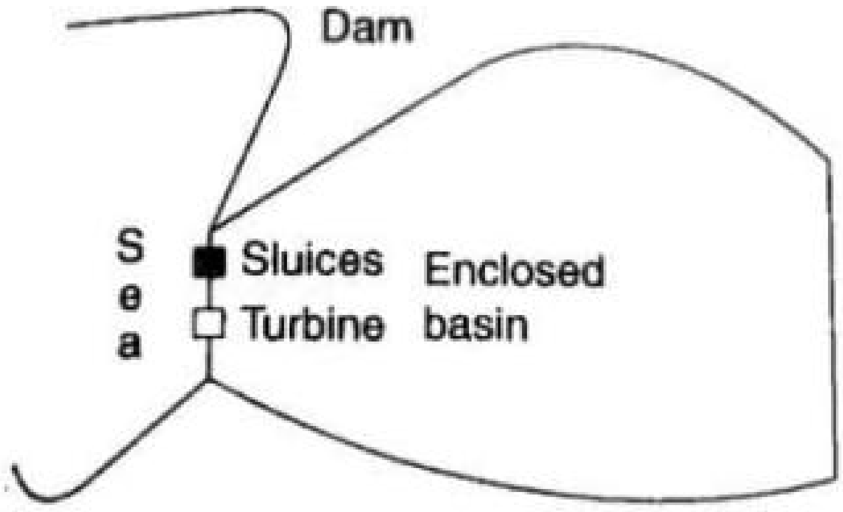
Working of Biogas Plant

The working principle of biogas plant can be explained in Figure 10.2. The various steps of working principle of biogas plants are as follows: 1. Cattle dung and water are mixed together thoroughly in equal proportion (in the ratio of 1:1) to form the slurry in the mixing tank. Then, this thoroughly in equal proportion (in the ratio of 1:1) to form the slurry in the mixing tank. Then, this slurry is poured into the digester via inlet chamber up to the cylindrical portion level of the digester.

2. The fermentation of slurry starts in the digester tank, and after completion of different anaerobic digestion processes, biogas is formed.
The gas continuously produced in digester tank is accumulated at the top of the digester in the dome or gas holder. Normally, the outlet gas valve remains closed, and hence, the accumulated biogas in the dome exerts pressure on the slurry which starts moving in the inlet and outlet chamber due to which the level of slurry drops in digester and increases in the outlet chamber. This process continues till the slurry reaches to highest possible level in the inlet and outlet chamber because of increased gas pressure. 4. If the gas valve is still kept closed the biogas will further get accumulated in the dome and develop high pressure enough in the gas to start escaping through the inlet and outlet chambers to the atmosphere. The biogas creates bubbles in the slurry in inlet and outlet chambers during its escape, and froth is also formed. 5. An increase in the volume of slurry in the inlet and outlet chambers helps to calculate the amount of biogas generated within the digester. 6. Gas pipe valve can be opened partly or fully to provide biogas for different applications. Under this situation, slurry level in the digester increases while the level in inlet and outlet chambers reduces. 7. When the gas is being taken out from the gas outlet at the top of the dome, the slurry from the outlet chamber is removed and equivalent amount of fresh slurry is inducted into the digester to continue the process of fermentation and the formation of the biogas. Therefore, more is the biogas required, more continuous will be the fresh slurry of cow dung and water required. The size of the digester tank also decides the amount of the gas that can be generated by the biogas plant.

Single-Basin System

- Simplest way of power generation and the simplest scheme for developing tidal power is the single basin arrangement.
- Single water reservoir is closed off by constructing dam or barrage.
- Gate, large enough to admit the water during tide so that the loss of head is small, is provided in the dam.



Single-basin system

Single-Basin System

The single basin system has two configurations

1.one way single basin system: the basin is filled by sea water passing through the sluice gate during the high tide..

When the water level in the basin is higher then the sea level at the low tide., then power is generated by emptying the basin water through turbine generators.

This type of systems can allow power generation only for about 5 hours and is followed by the refilling of the basin.

Power is generated till the level of falling tides coincides with the level of the next rising tide.

Single-Basin System

2. two way single basin: this system allows power generation from the water moving from the sea to the basin, and then, at low tide, moving back to the sea.

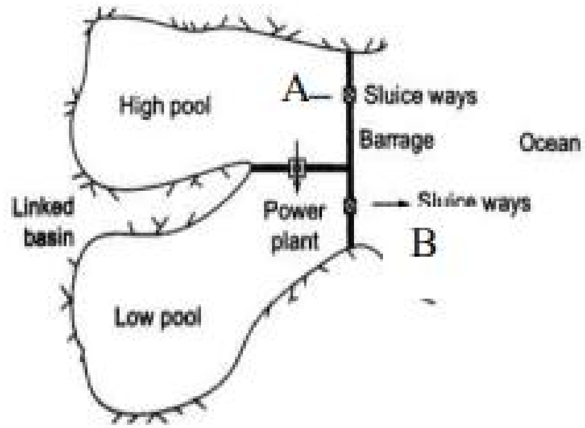
This process requires bigger and more expensive turbine.

Single basin system has the drawbacks of intermittent power supply and harnessing of only about 50% of available tidal energy.

Double cycle system: It requires two separate but adjacent basins. In one basin called "upper basin" (or high pool), the water level is maintained above that in the other, the low basin (or low pool). Because there is always a head between upper and lower basins, electricity can be generated continuously, although at a variable rate.

TWO BASIN-LINKED BASIN

- HIGH POOL
  - FILLED DURING HIGH TIDE
- LOW POOL
  - EMPTIED DURING LOW TIDE



In this system the turbines are located in between the two adjacent basins, while the sluice gates are as usual embodied in the dam across the mouths of the two estuaries. At the beginning of the

In this system the turbines are located in between the two adjacent basins, while the sluice gates are as usual embodied in the dam across the mouths of the two estuaries. At the beginning of the flood tide, the turbines are shut down, the gates of upper basin A are opened and those of the lower basin B are closed. The basin A is thus filled up while the basin B remains empty. As soon as the rising water level in A provides sufficient difference of head between the two basins, the turbines are started. The water flows from A to B through the turbines, generating power. The power generation thus continues simultaneously with the filling up the basin A. At the end of the flood tide when A is full and the water level in it is the maximum, its sluice gates are closed. When the ebb tide level gets lower than the water level in B, its sluice gates are opened whereby the water level in B, which was arising and reducing the operating head, starts falling with the ebb. This continues until the head and water level in A is sufficient to run the turbines. With the next flood tide the cycle repeats itself. With this twin basin system, a longer and more continuous period of generation per day is possible. The small gaps in the operation of such stations can be filled up by thermal power. The operation of the two basin scheme can be controlled so that there is a continuous water flow from upper to lower basin. However since the water head between the basins varies during each tidal cycle, as well as from day to day, so also does the power generated. As in the case with single basin scheme, the peak power generation does not often correspond in time with the peak demand. One way of improving the situation is to use off-peak power, from the tidal power generators or from an alternative system, to pump water from the low basin to the high basin. An increased head would then be available for tidal power generation at times of peak demand. This is very similar to pumped storage system in hydro-electric power stations.

6. Factors affecting Biogas Generation

- pH or the hydrogen ion concentration(6.5-7.5)
- Temperature (33-35°C)
- Total solid content of the feed material
- Loading rate
- Seeding
- Uniform feeding
- Diameter to depth ratio
- Carbon to nitrogen ratio
- Nutrients
- Mixing or stirring or agitation of the digester
- Retention time or rate of feeding
- Type of feed stocks

PRINCIPLE OF OTEC

- Normally used working fluids are
- Propane for high temperature ocean surface water
- Low boiling point liquid ammonia for low temperature ocean surface water
- In open cycle OTEC, warm ocean surface water is pumped into a low pressure boiler to boil water and produce steam.
- Then, the steam is used to drive steam turbine to produce electricity
- To condense steam, cold deep sea water is used

OTEC Plants

- Two different types:

1. Land Based Power Plant
2. Floating Power Plant

Land Based Power Plant

- Will consist of a building constructed on the shore
- It requires laying of pipes
- One pipe to collect warm ocean water

- One pipe to collect warm ocean water
- Second pipe lay down on the slope deep into the ocean to collect cold water
- Third pipe is used as outlet to discharge used water again to deep down ocean

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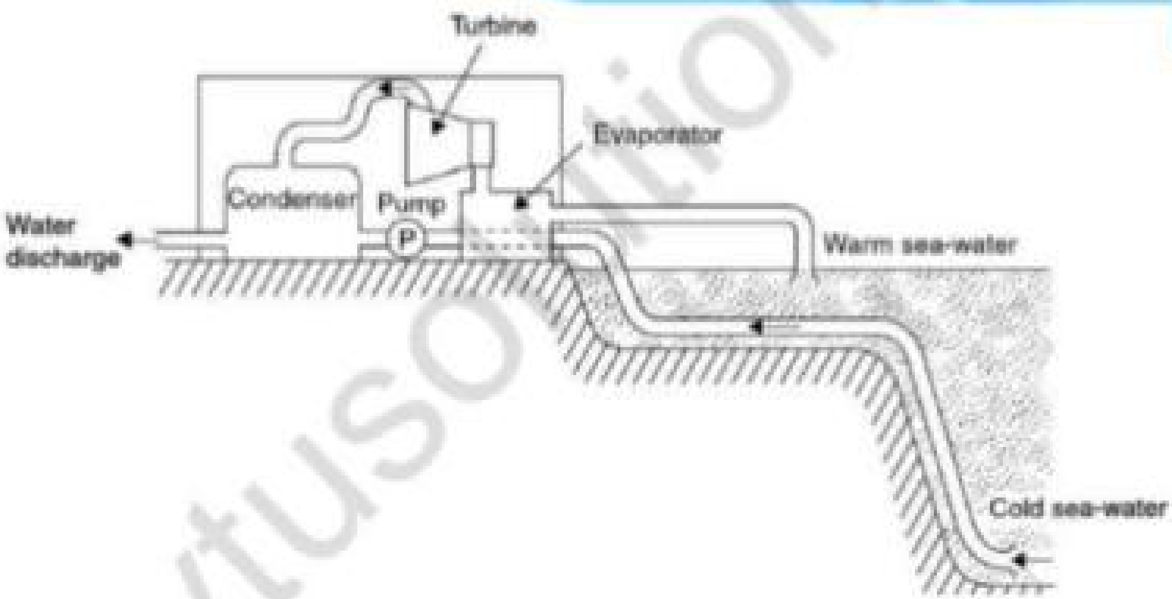
Land based OTEC



6) Classify wave energy devices. With neat sketches, explain the different types of wave energy devices used to harness wave energy.[10 Marks]

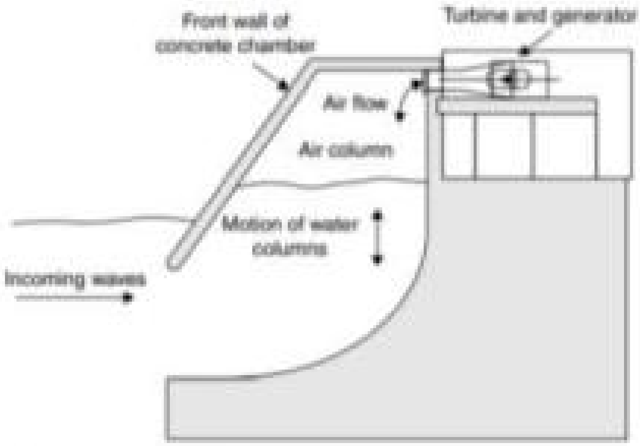
There are three basic technologies for converting wave energy to electricity. They are as follows: 1. Terminator devices: It is a wave energy device oriented perpendicular to the direction of the wave and has one stationary and one moving part. The moving part moves up and down like a car piston in response 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 bobb in type motion and drives a built-in turbine generator system to generate electricity. Aqua BuOY 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.

a) Float or Buoy Devices

A series of anchored buoys rise and fall with the wave that creates mechanical energy to drive electrical generator for generation of electricity, which is transmitted to ocean shore by underground cables.

b) Oscillating Water Column Devices

An oscillating water column device (OWC device) is shown in Figure 12.5. 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. Wells' turbines as shown in Figure 12.6 are used to extract energy from the reversing air flow. It has the property of rotating in the same direction regardless of the direction to the airflow.



c) Pendulum System

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

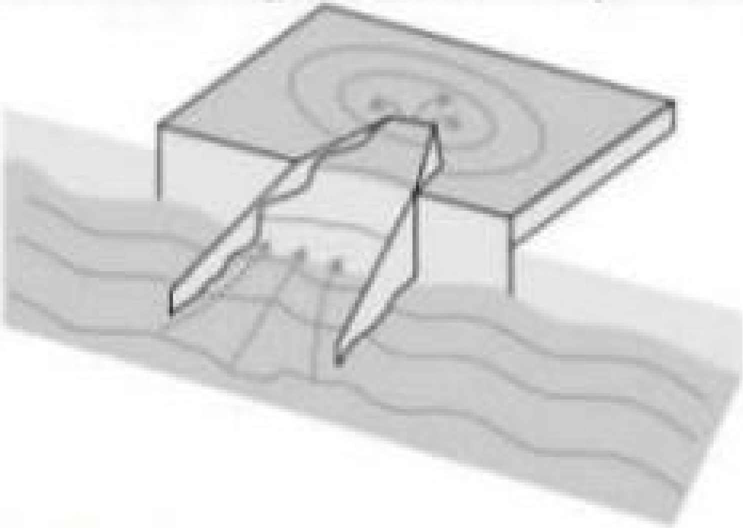
d) TAPCHAN (Tapered Channel)

It has a tapered channel connected to a reservoir constructed above the sea level at a height of

an electric generator

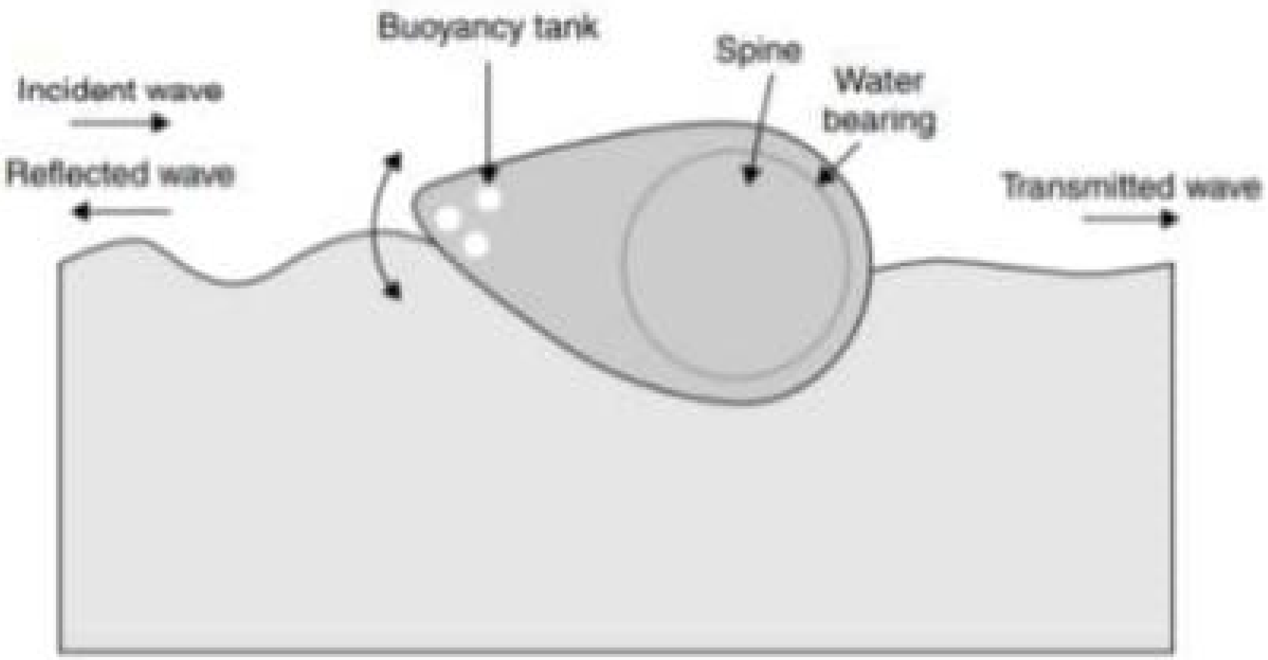
d) TAPCHAN (Tapered Channel)

It has a tapered channel connected to a reservoir constructed above the sea level at a height of
3–5 m. They are relatively low power output devices and suitable for deep-water shore line and low tidal range. It is a very simple device. Waves collect into a channel, which tapers into a large reservoir. The potential energy of water stored in the reservoir is extracted by releasing the reservoir water back to the sea through a low head Kaplan turbine coupled to an electrical generator.



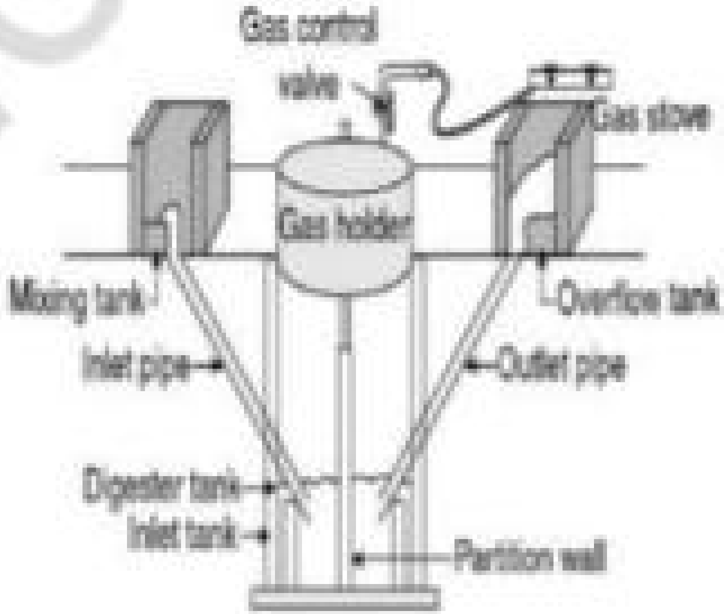
e) Salter's Duck System

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.


Buoyancy tank
Spine
Water bearing
Incident wave
Reflected wave
Transmitted wave

Floating dome type

- The different parts are:
- 1.Mixing tank
- 2.Digester tank
- 3.Inlet pipe & inlet tank
- 4.Floating dome
- 5.Outlet pipe & overflow tank
- 6. Gas outlet pipe
- 7.Gas control valve



Working

- Slurry (mixture of equal quantities of biomass and water) is prepared in the mixing tank.
- The prepared slurry is fed into the inlet chamber of the digester through the inlet pipe.
- The plant is left unused for about two months and introduction of more slurry is stopped.
- During this period, anaerobic fermentation of biomass takes place in the presence of water and produces biogas in the digester.
- Biogas being lighter rises up and starts collecting in the gas holder. The gas holder now starts moving up.

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Contd.

- The gas holder cannot rise up beyond a certain level. As more and more gas starts collecting, more pressure begins to be exerted on the slurry.
- The spent slurry is now forced into the outlet chamber from the top of the inlet chamber.
- When the outlet chamber gets filled with the spent slurry, the excess is forced out through the outlet pipe into the

CLOSED CYCLE, OPEN CYCLE AND HYBRID CYCLE

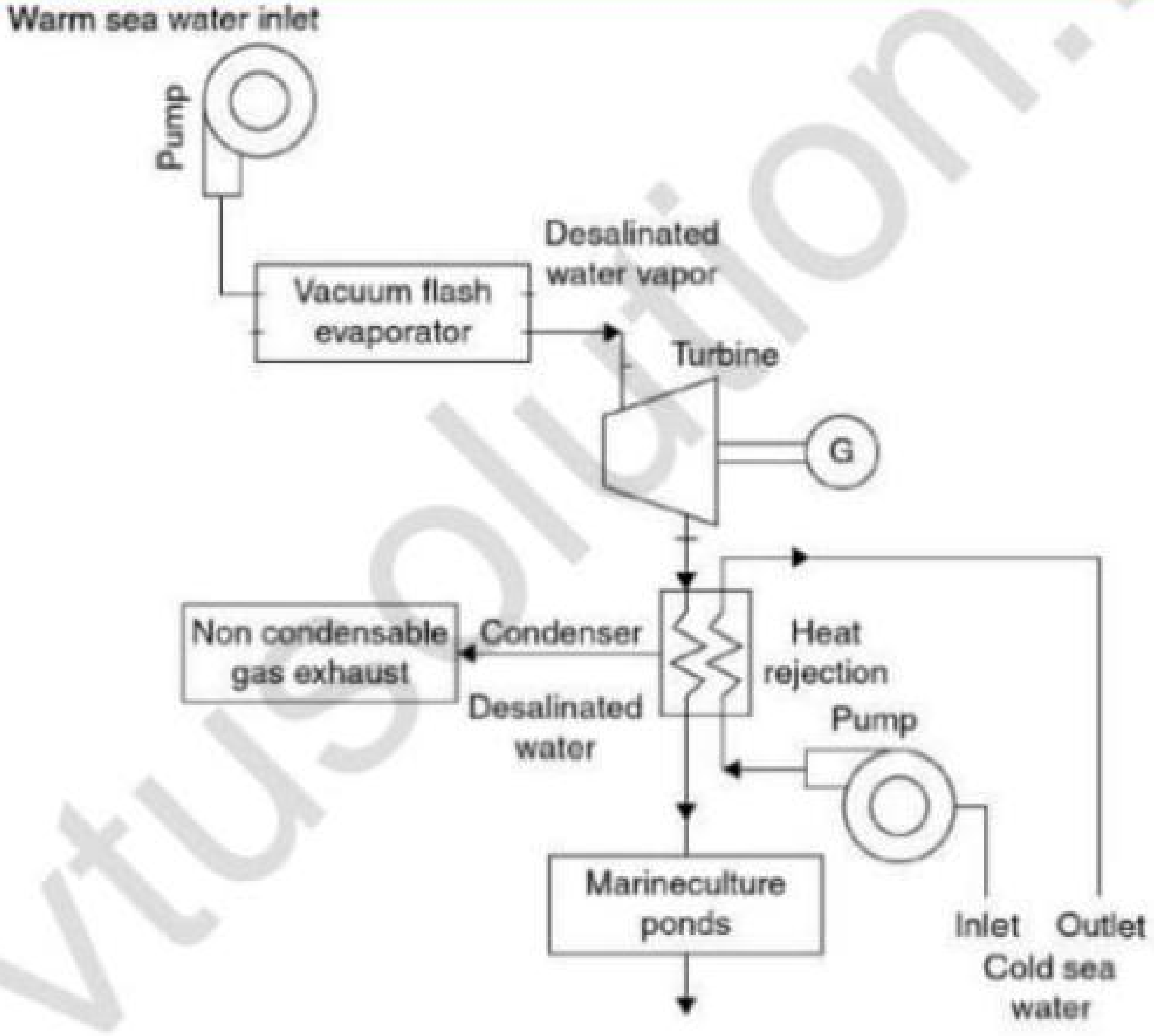
There are three types of OTEC cycle designs, namely open cycle, closed cycle, and hybrid cycle.

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.

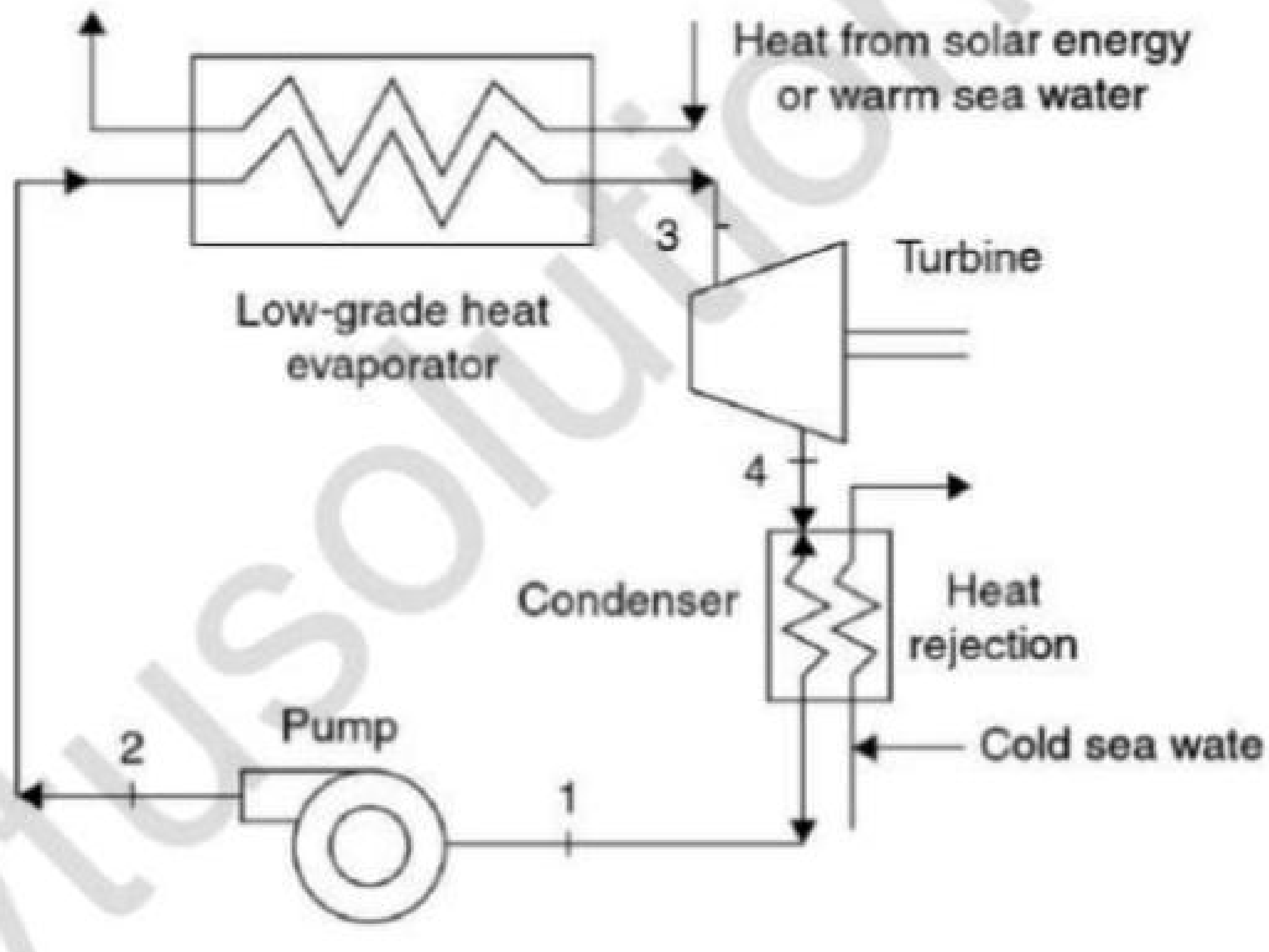
2. In closed cycle, organic fluid flows in a separate closed-cycle loop called organic Rankine cycle. Warm sea surface water pumped through another pipe vapourizes working fluid in heat exchangers to drive turbine generator, The fluid vapour condenses into liquid form by deep sea water pumped in condenser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

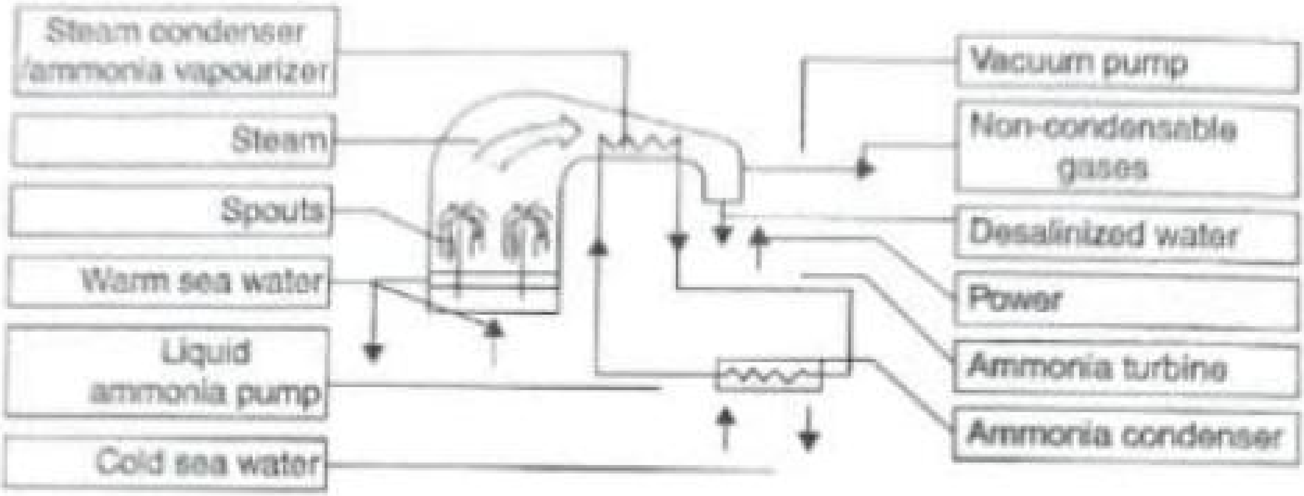
Open cycle OTEC PLANTS



CLOSED CYCLE OTEC



OTEC HYBRID CYCLE



As shown in Figure , 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.

BASIC **RANKINE** CYCLE

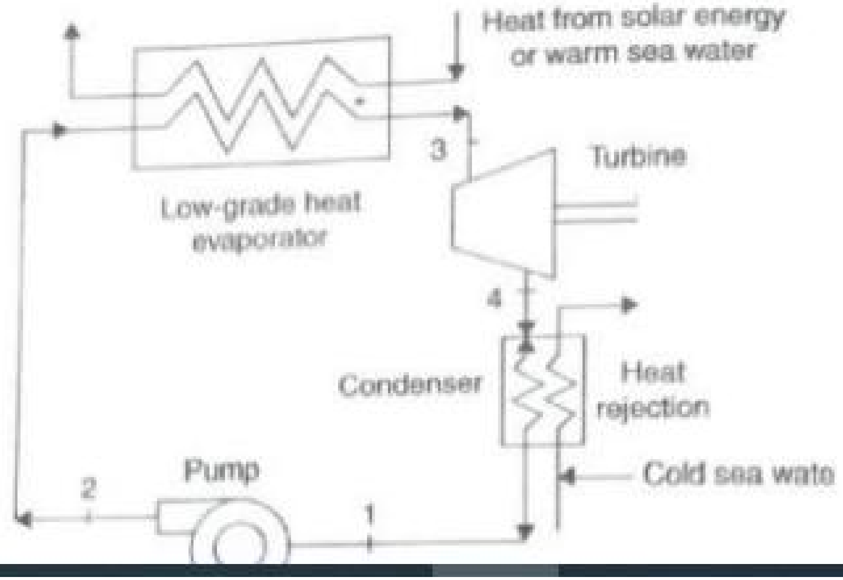
The basic Rankine cycle shown in Figure consists of the following:

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.



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.