MODULE-05

(a) Sea Wave Energy.

I. Introduction:-

The energy in sea waves mainly comes in an irregular and oscillating form at all times of the day and night.

Kinetic energy, the energy of motion, in waves is tremendous. Waves get their energy from the wind. Wind comes from solar energy.

As long as the sun shines, wave energy will never be depleted. It varies in intensity, but it is available all the times.

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.

II. Motion in the SEA Waves:

* When the wind blows across smooth water surface, air particles from the wind grab the water molecles they touch.
* Friction between the air and the water creates capillary waves [small wave ripples].
* Surface tension acts on these ripples to restore the smooth surface & thereby waves are formed.
* Combination of forces due to the gravity, sea surface tension & wind intensity are main factors for origin of sea waves.
* Sea waves have a regular shape at far distance from the fetch & this phenomenon is called swell.
* Wave formation makes the water surface further rough & the wind continuously grips the roughened water surface & thus, waves are intensified.

* Wave is a forward motion of energy, In the true sense, the seawater does not move forward with a wave.

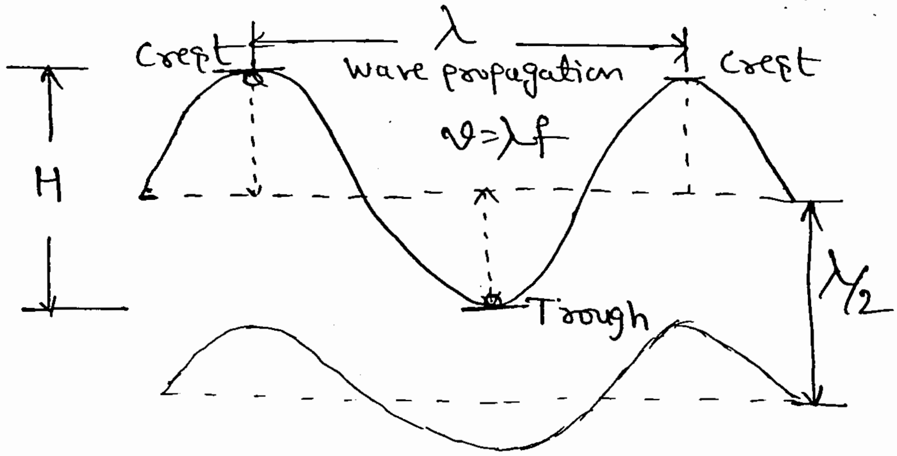


Figure: Sea wave propagation

Wave parameters

1. Crest : The peak point/Maximum height on the wave is called the crest.
2. Trough : The valley point/Lowest point on the wave called Trough.
3. Wave height (H): It is a vertical distance between the wave crest and the next trough (m).
4. Amplitude (a): It is defined as $\frac{H}{2}$ (m).
5. Wave length (λ): It is the horizontal distance either between the two successive crests or trough of the ocean waves (m).
6. Wave propagation velocity (v): The motion of seawater in a direction (m/s). $\boxed{v=\lambda f}$
7. Wave period (T): 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. $f=\frac{1}{T}$ (cycles/sec).

III Power associated with SEA waves: ** Imp.

As concluded by researchers through linear wave motion theory, that kinetic & potential energy (E) of a wave per meter of crest & unit of surface can be approximated as

$$\therefore E = \frac{\rho g a^2}{2} \longrightarrow (1)$$

where ρ = Density of water

g = gravitational accelaration

a = amplitude of wave $= \frac{H}{2}$

H = Height of wave.

Let K = dispersion relation in deep water, given as

$$K = \frac{\omega^2}{g} \longrightarrow (2)$$

group velocity $V_g = \frac{\omega}{2K} = \frac{\cancel{\omega}}{2\frac{\omega^{\cancel{2}}}{g}} = \frac{g}{2\omega} \longrightarrow (3)$

$\therefore$ power (P) = Energy × group velocity

$$= E \times V_g$$

$$P = \frac{\rho g a^2}{2} \times \frac{g}{2\omega}$$

$$\boxed{P = \frac{\rho g^2 a^2}{4\omega}} \longrightarrow (4)$$

Let T = wave period

$$T = \frac{2\pi}{\omega} \text{ or } \omega = \frac{2\pi}{T} \;\&\; a = H/2$$

$$\therefore P = \frac{\rho g^2 \left(\frac{H}{2}\right)^2}{4 \times \frac{2\pi}{T}} = \frac{\frac{\rho g^2 H^2}{4}}{\frac{4 \times 2\pi}{T}} = \frac{\rho g^2 H^2}{4} \times \frac{T}{4 \times 2\pi}$$

$$\boxed{P = \frac{\rho \cdot g^2 H^2 T}{32\pi}} \longrightarrow (5)$$

Note 1) wave power is directly proportional to the square of wave height.

2) For irregular waves of Height (H) & period (T), then $\boxed{P_{irregular} = 0.4 \text{ kW/m}}$.

3) When water depth is larger than half the wavelength, then wave power approximated as

$$\boxed{P = 0.5\, H^2 T \text{ kW/m}}$$

4) The relationship between the wavelength & the time period can be approximated as

$$\lambda = 1.56 T^2$$

5) Velocity of wave propagation $v = \lambda/T$.

Problems on wave power:

1.) A 2-m sea wave has a 6s period & occurs at the surface of 100-m deep water. Assume sea-water density equals to 1025 kg/m³. Calculate the energy & power densities of the wave. Determine velocity of wave propagation if relation between λ & $T \approx \lambda = 1.56 T^2$

Imp.

Soln; Given data; $H = 2m$ $T = 6$ $\rho = 1025 \text{ kg/m}^2$ $g = 9.81$ (Assume)

Velocity of wave propagation $v = \lambda/T$

$$\lambda = 1.56 T^2 = 1.56 \times 6^2 = 56.16 \text{ m}.$$

$$\therefore v = \frac{56.16}{6} = 9.36 \text{ m/s}. \qquad a = \frac{H}{2} = \frac{2}{2} = 1$$

$$E = \frac{\rho g a^2}{2} = \frac{1025 \times 9.81 \times \left(\frac{2}{2}\right)^2}{2} = 5027.625 \text{ J/m}^2$$

$$\text{Power Density} = \frac{E}{T}$$

$$P = \frac{5027.625}{6}$$

$$\boxed{P = 837.9375 \ W/m^2}$$

2.) An ocean swell, a few kilometers away from the coastline & in deep seawater, has wave height of 3m & wave period of 8s. Obtain power of the wave energy per unit of wave crest length.

Soln;

$P = 0.5 H^2 T$ Data given $H = 3$, $T = 8$

$P = 0.5 \times 3^2 \times 8$

$$\boxed{P = 36 \ KW/m}$$

IV. Advantages & Disadvantages of Wave power. ※※ Imp

Advantages:

1. Wave energy is clean source of renewable energy with limited environmental impacts
2. Environment friendly
3. Sea waves have high energy densities
4. Abundant & widely available
5. Variety of ways to Harness energy.
6. It has no greenhouse gas emissions or water pollutants
7. Operating cost is low.
8. Operating efficiency is optimal
9. No Damage to land
10. Damage to ocean shoreline is reduced
11. Less dependency on foreign oil companies
12. Easily predictable.

Disadvantages:

1. High construction cost
2. Suitable to certain locations
3. Effect on marine ecosystem
4. Irregular wavelength.
5. Weak performance in Rough weather
6. Noise & Visual pollution
7. Damage to the devices from strong st..ms and corrosion create problems

V. Wave Energy Availability: [short Notes].

Worldwide:

→ The density of water is about 800 times higher than air, therefore the amount of energy available in ocean waves is tremendously high, hence it is considered as a renewable, zero emission source of power.

→ Estimates of the global ocean wave energy are more than 2TW (which means 17,500 TWh/year) according to the World energy council.

→ Wave energy is converted into electricity by placing wave energy converter on the surface of the ocean.

→ Sea wave energy technologies rely on the up & down motion of waves to generate electricity.

→ Several installation have been built in Scotland, Portugal, Norway, the USA, China, Japan, Australia & India.

A few installation of wave power converts are as follows.

1. The first wave-power patent was for a 1799 proposal by a Parisian named Monsieur Girard

& his son got patented the first wave power converter in 1979 to use direct mechanical action to drive pumps, saws, mills or other heavy machinery.

2. During the first decades of the 19th century, a device was put in operation in Algeria that captured wave oscillation & transformed it into usable form by using a system of cams & gears.

3. A 10KW complaint flap pilot plant was installed in the Baltic sea in 1917 & later on dismantle.

4. Pelemis became the world's first offshore wave machine to generate electricity & fed into the grid, when it was first connected to the UK grid in 2004.

5. Salter Duck wave converter was developed around 1980 in UK.

6. A 120 KW (Oscillating wave column) prototype (The mighty Whale) with 3 OWCs in a row has been operating since 1998 [1.5 km off Nansei Town, Japan) at 40m depth.

7. A 2MW system off the coast of portugal.

8. The prototype (wave Dragon) is deployed in Nissum Bredning, an inlet in the northern part of Denmark.

9. A 40m long prototype [McCabe Wave pump] was deployed in 1996 off the coast of Kilbaha, country Clare, Ireland.

10. A typical 30MW (pelamis) installation would occupy a square kilometre of ocean & provides sufficient electricity for 20,000 homes.

11. A 750 KW project [Pelamis] off Islay, Scotland.

12. 2 MW (Pelamis) project off the coast of Vancouver Island, Canada.

13. A 5MW (world's first commercial wave energy plant) developed by Wave Gen is located is Isle of Islay, Scotland.

Wave energy availability India ※※ Imp.

→ The coastal area of Maharastra has an annual wave potential ranging between 4KW/m & 8KW/m wavefront, which is quite high as 12-20KW/m during the monsoon.

→ The wave energy potential of the most feasible sites in Maharashtra given in table 1 for offshore location.

Table 1. offshore location of Wave power in Maharashtra.

SL NO	Site	Average Wave power (KW/m) Annual	Average Wave power (KW/m) June - August
1.	Malvan Rock	6.91	16.73
2.	Kura Inset	5.79	13.74
3.	Redi	6.35	16.57
4.	Vengurla Rock	8.01	20.61
5	Square Rock	6.79	16.64

→ Coastal average power location site in Maharas... is given in Table 2.

Table 2. Coastal Average Power Location site Maharashtra

SL NO	Site	Average power (KW/m) Annual	Average wave power (KW/m) June - August
1	Vijaydurg	5.86	13.58
2	Girye	5.90	14.21
3	Ambolgarh	5.74	13.48
4	Pawapoint	5.36	13.10
5	Kunkeshwar	5.64	13.35
6	Wagapur	5.70	13.10

→ The Vengurla & Malvan rocks & Redi are on the top among the offshore locations.

→ In the coastal location, however, pawa & Ratnagiri top the list followed by Girye & Miyet point.

→ Vizhinjam fishing harbour, kerala, is the site of a unique demonstration plant that converts sea wave energy to electricity & is given to the local grid, this plant has oscillating water column (OWC) converter in 1990.

VI. Devices for Harnessing Wave energy: pakka ※※ vvImp.

There are four basic technologies for converting wave energy to electricity, They are.

(i) Terminator devices: It is a wave energy device oriented perpendicular to the direction of the wave & has one stationary & one moving part. The moving part moves up & down like a car piston in response to ocean waves & pressurizes air to drive turbine.

example: oscillating water column (OWC)

power ratings of 500kW to 2MW, depending on the wave parameters & the device Dimensions.

(ii) Attenuator Devices: These devices are oriented parallel to the direction of the waves & are long multi-segment floating structures,

example: Pelamis wave energy converter.

(iii) Point obsorber devices: 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.

example:- AquaBuoy WEC.

(iv) Overtopping Devices: These devices have reservoirs like a dam are filled by incoming waves, causing a slight build-up of water pressure.

example: Salter Duck WEC.

1. Float or Buoy Devices:

A series of anchored buoys rise & 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.

2. Oscillating Water Column Devices.

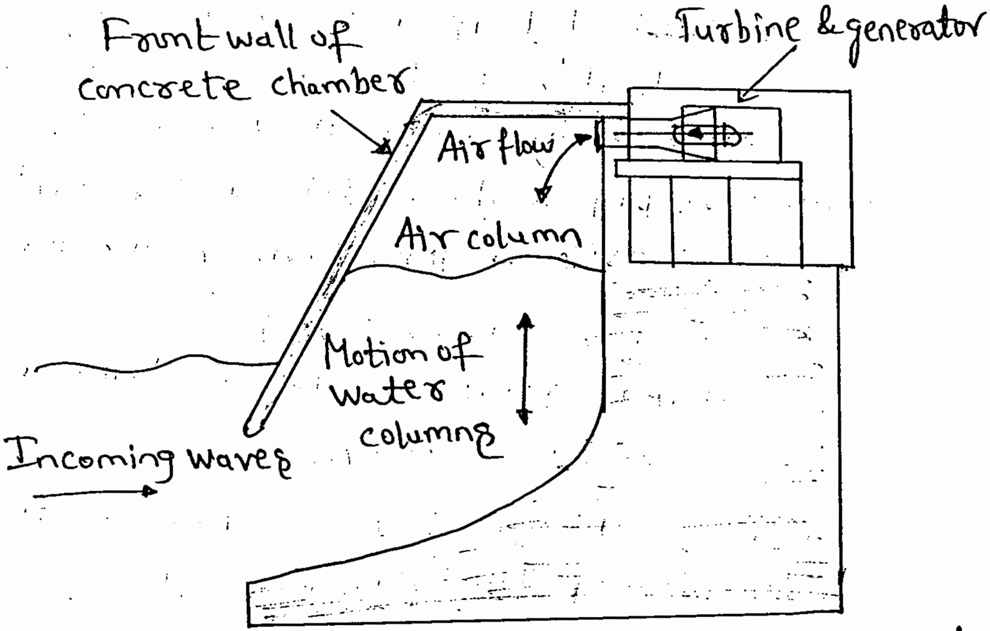


Figure 1. Schematic of an oscillating water column device.

* 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 & 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.
* It is a concrete structure partially submerged in seawater & encloses a column of air on top of a column of water.
* When sea wave impinge on the device, the water columns in partially submerged chamber rise & fall.
* This wave action alternatively compresses & depressurizes the air column, which is allowed to flow to & from the atmosphere via a turbine.
* The energy can then be extracted from the system & used to generate electricity.

3. Pendulum System:-

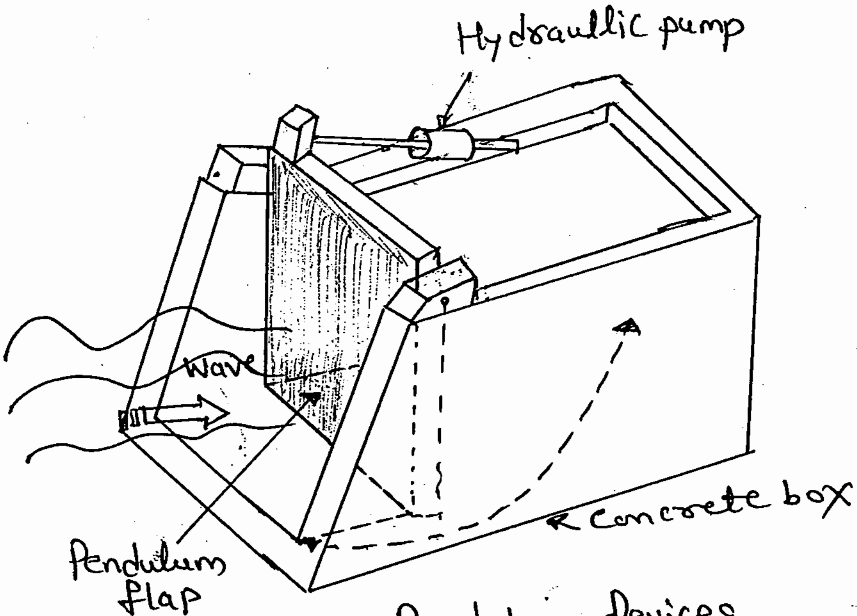


Figure 2. Pendulum Devices.

* The pendulum system is a shoreline device that consists of a parallel piped concrete box, which is open to the sea at one end as shown in Figure 2.
* The pendulum flap swings back & forth by the action of waves, is then used to power a hydraulic pump & an electric generator.

4. Tapchan [Tapered channel] Device;

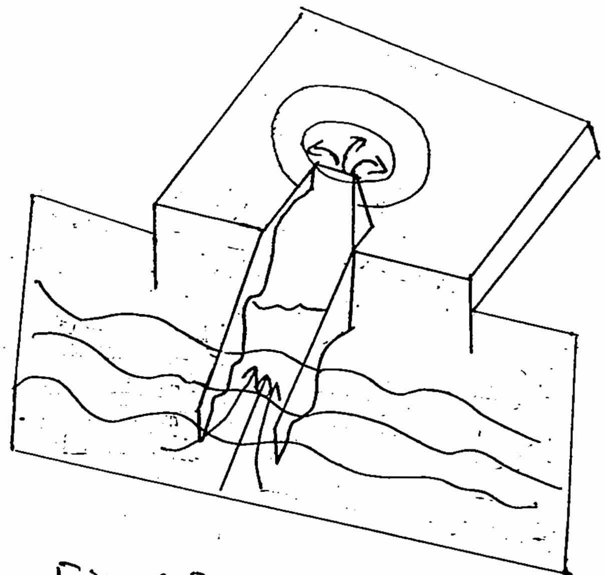


Figure.3 TAPCHAN Device.

* It has a tapered channel connected to a reservoir constructed above the sea level at a height of 3-5m.
* It is low power output devices & 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. as the wave width decreases, the wave amplitude increases according to the principle of conservation of energy & this enables the waves to travel up a ramp & pour into the reservoir as shown in Figure 3.

5. Salter's Duck System:-

* It was invented in Scotland in 1970 to extract mechanical energy from the ocean waves.
* It is example for overtopping devices.
* It is an egg-shaped device that moves with the motion of waves.

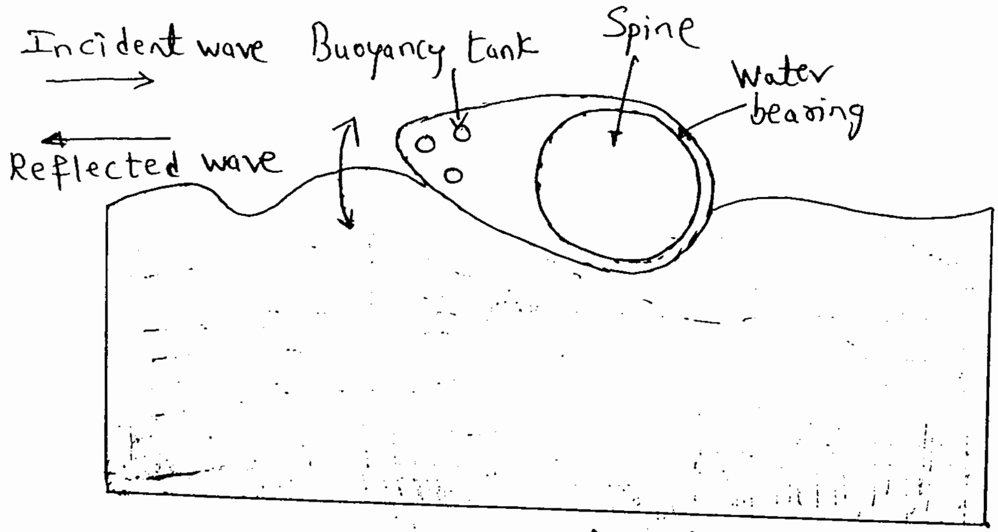


Figure 4. Salter duck.

* As the salter duck moves up & down on the sea waves, pendulum connected to electrical generator swings forward and backward to generate electricity.

6. Offshore Wave Dragon system;

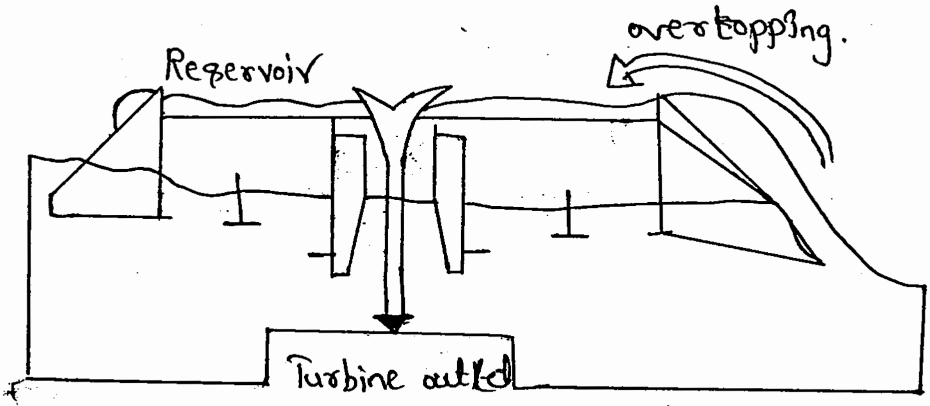


Figure 5. off shore wave dragon devices

* The wave dragon is an overtopping device that elevates ocean waves to a reservoir above sea level.
* The basic idea of this system consists of two large 'arms' that focus waves up a ramp into a reservior. The water returns to the sea by the force of gravity via a low head hydro turbine that drives an electric generator

7. Bristol Cylinder:

The bristol cylinder operates under the sea level as shown in Figure 6.

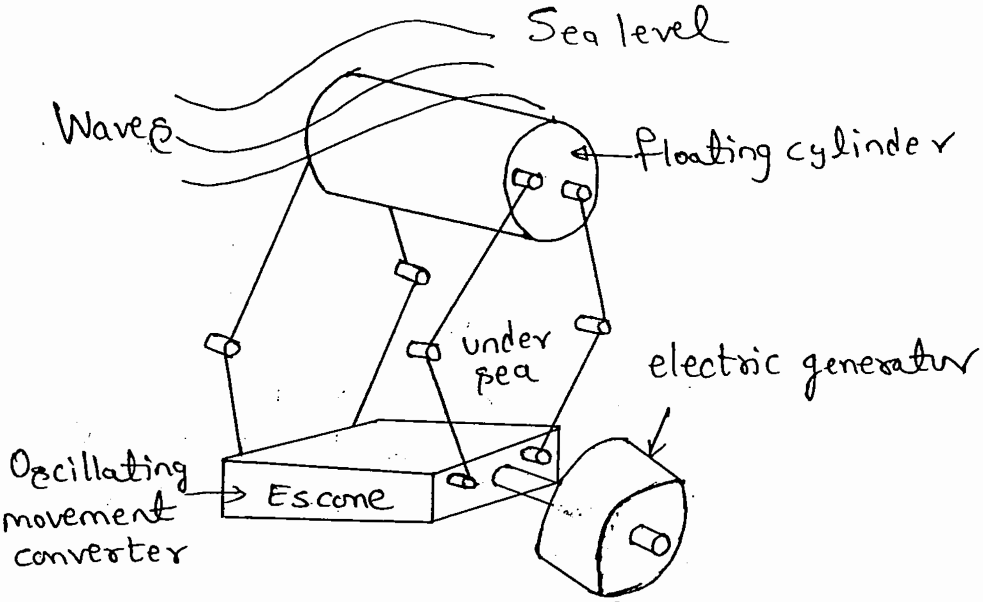


Figure. 6

* 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.

8. Archimedes Wave swing Devices.

(b) Ocean Thermal Energy:

I. Introduction:-

* Ocean thermal energy conversion (OTEC) is a method to produce electricity by using the temperature differences between warm ocean surface and cool deep ocean water to run a heat engine.
* OTEC sites that are located between the tropic of cancer and Tropic of Capricorn found to be best location.
* OTEC is an energy technology that converts solar radiation to electric power through heat of ocean water.

II Principle of ocean thermal energy conversion:- ✗

* The basic principle of ocean thermal energy conversion (OTEC) works on two cycles i.e., open & closed cycle.
* The warm water from the ocean surface is collected & pumped through the heat exchanger to heat & vapourize a working fluid, & it develops pressure in secondary cycle. Then, the vapourized working fluid expands through a heat engine coupled to electric generator that generates electrical power. Working fluid vapour coming out of heat engine is condensed back into liquid by a condenser. The liquid [working fluid] is pumped again through heat exchanger & cycle repeats — known as closed cycle OTEC.
* In an open-cycle OTEC, warm ocean surface water is pumped into a low-pressure boiler to boil & 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.

III. Ocean thermal energy conversion plants. Imp

There are two different kinds of OTEC power plants namely

(i) Land - Based power plant

(ii) Floating power plant.

(i) Land - based Power plant:

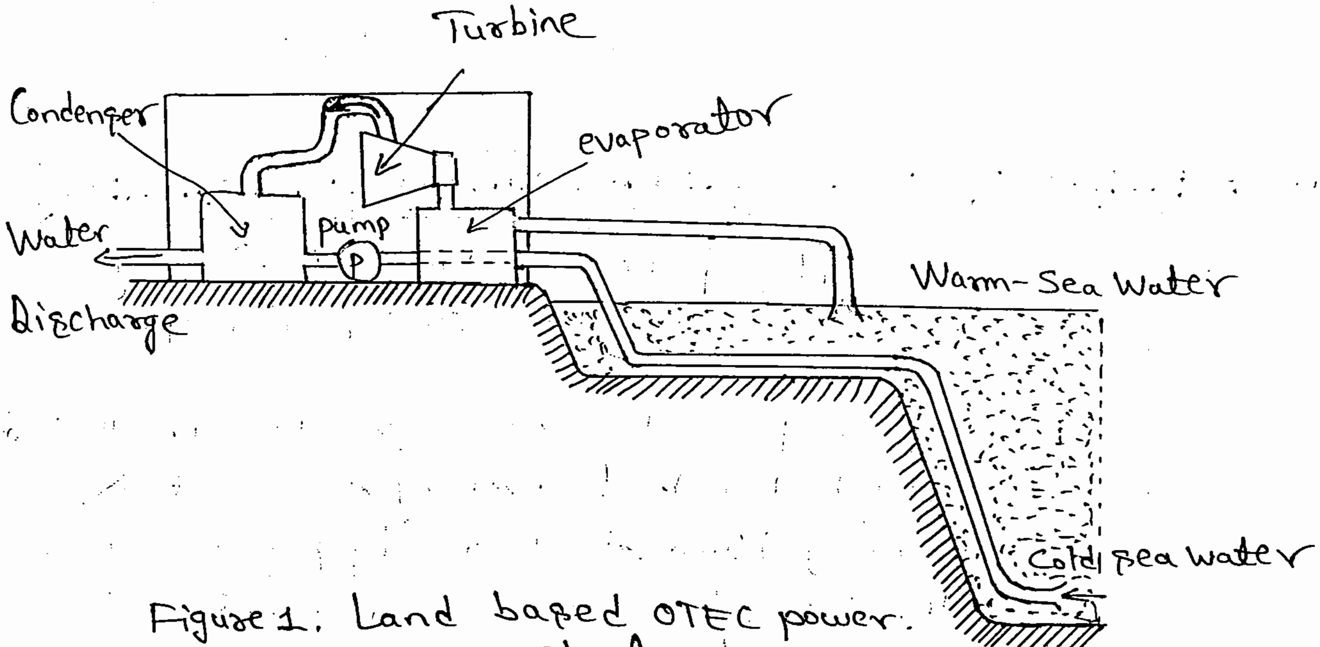


Figure 1. Land based OTEC power plant.

* The Land based power plant will consist of a building shown in Figure 1.
* It is constructed on shore and accomodates all parts of OTEC plants.
* It requires Laying down Long pipes from plant side 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 & land-based plant is also very expensive.
* Large electricity is used to pump water through long pipes, the net electricity reduces considerably.
* Land-based OTEC plant has the advantages of savings on electrical transmission line & connectivity to electrical power grid.

(ii) Floating power plant:

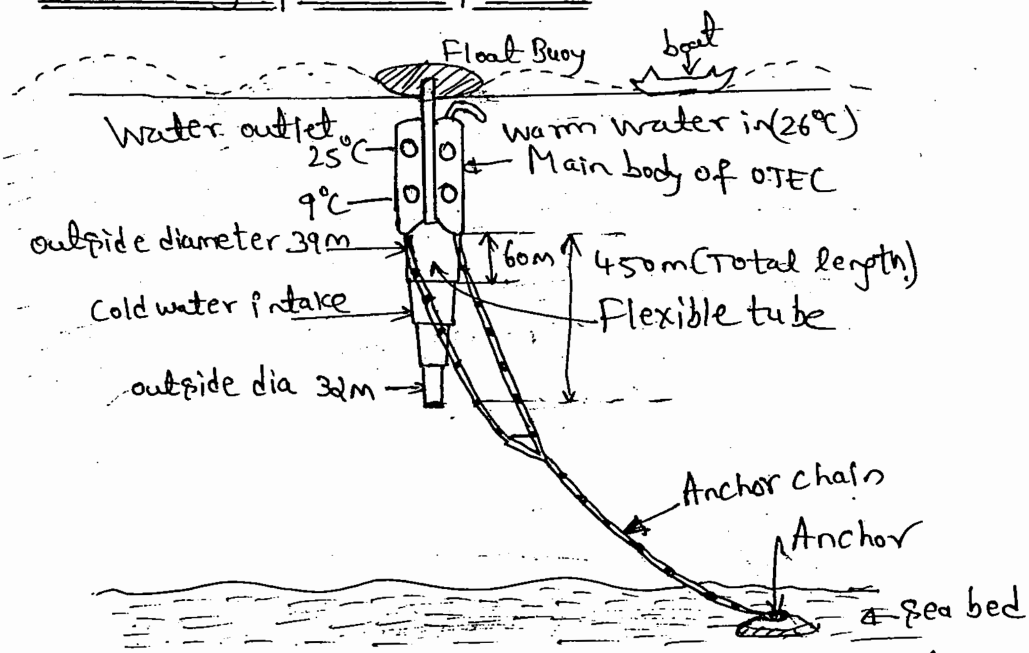


Figure 2. Floating OTEC Power plant.

* Floating power plant is built on a ship platform exactly where required temperature gradient sufficient for OTEC plant is available.
* It works similar to 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.

* High installation cost of long underwater power cables & its inefficiency and many other associated problems,
* Floating OTEC are considered for the production of fuels, such as hydrogen, on the platform itself by the electrolysis of water.
* If 1000 meters 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.

IV Basic Rankine cycle and its working:-

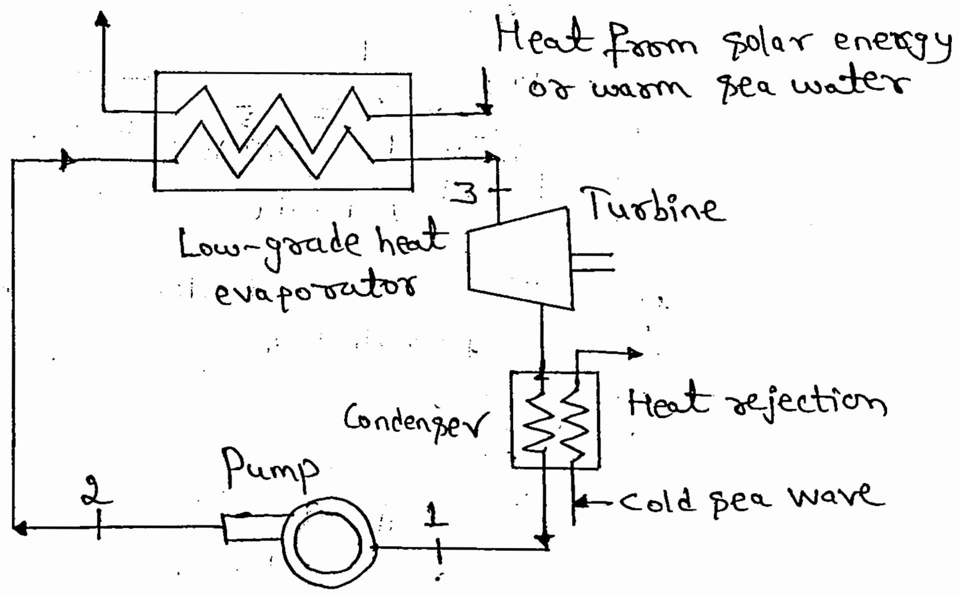


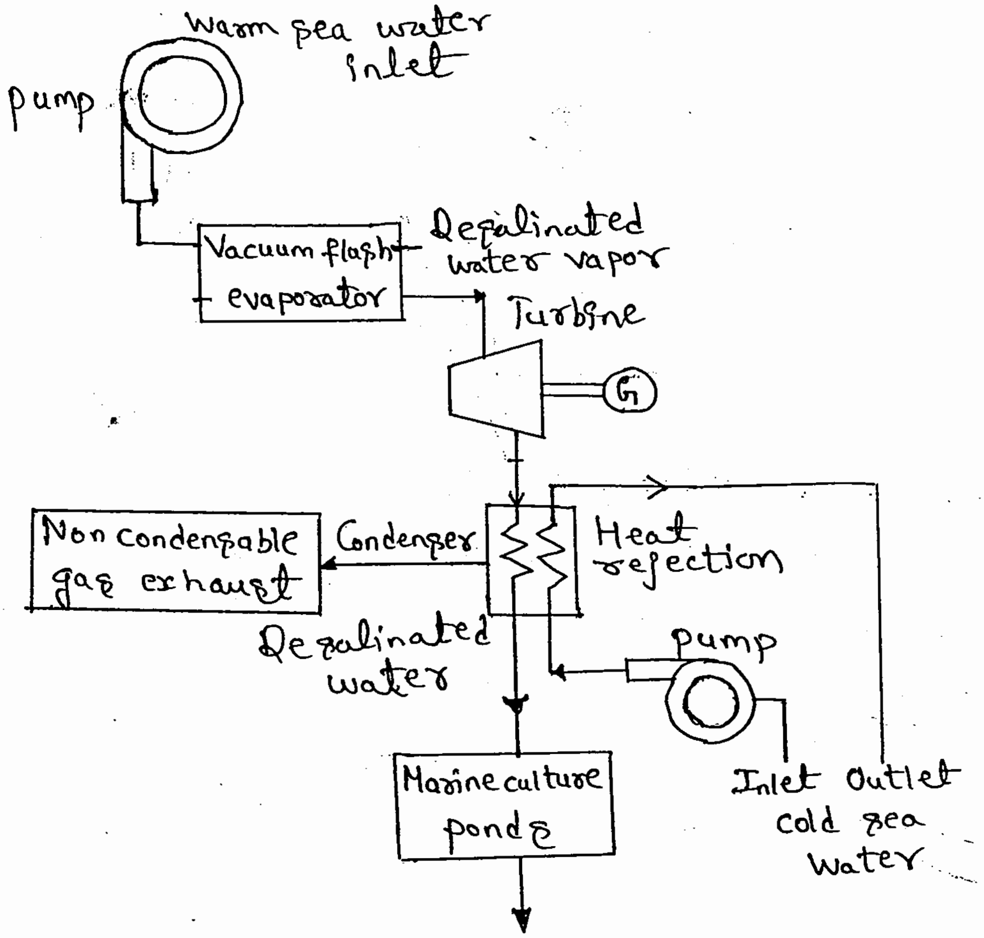
Figure 3. OTEC Rankine cycle

* The basic rankine cycle shown in figure 3 consists of the following
  1) evaporator
  2) turbine expander.
  3) condenser
  4) pump.
  5) 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 electorical generator to generate electrical power.
* The liquid fluid is again pumped through evaporator & cycle repeats.
* As temperature difference between high & low-temperature ends is large enough, the cycle will continue to operate & generate power.

VI. Closed cycle, Open cycle and Hybrid cycle

1. Open-cycle OTEC.



* 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 vapor/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 & for other work, and the remaining large amount of electricity is stored as net electrical power.

* The steam with many gases 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 & exhausted simultaneously.

* The warm ocean surface water is continuously pumped into evaporator & cycle repeats.

2. Closed cycle OTEC plant;

* The schematic of closed-cycle OTEC is shown in figure 5.

* Working fluid is pumped through heat exchangers in a closed loop cycle which is perfectly leakage proof.

* Warm sea water transfer its heat energy to working fluid in heat exchanger & working fluid vapourizes.

* Warm sea surface water is pumped through separate pipe in heat exchanger in close contact with fluid closed loop cycle.
* The fluild vapour makes the turbine to rotate & drive an electrical generator to produce electricity.
* Fluild vapour leaving the turbine is coolend & 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 fluild.

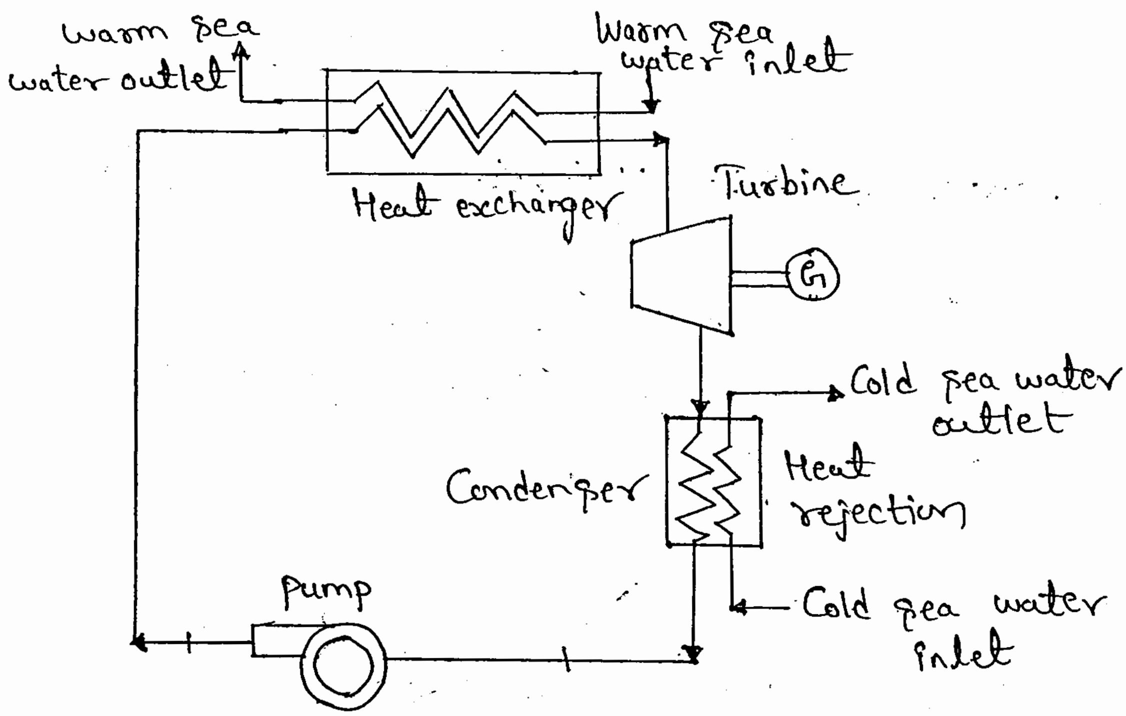


Figure 5. Closed cycle OTEC plant.

3. <u>OTEC Hybrid cycle</u>:-

* Hybrid cycle combines the features of both closed-cycle and open-cycle systems.
* Warm sea water is pumped into a vaccum chamber where it is used to flash and produces steam.

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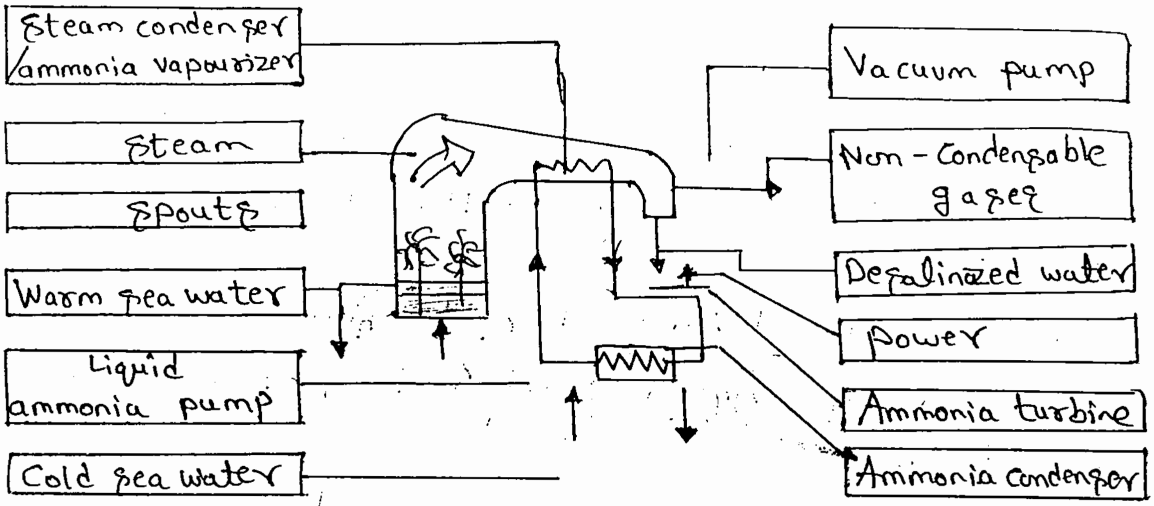

Figure 6. Hybrid OTEC cycle.

* Working fluild in another closed cycle loop is evaporated & vapourized by steam in vaccum chamber. The fluild vapour rotates the turbine & drive an electric generator to produce electricity

VI Carnot cycle:- vv Imp.

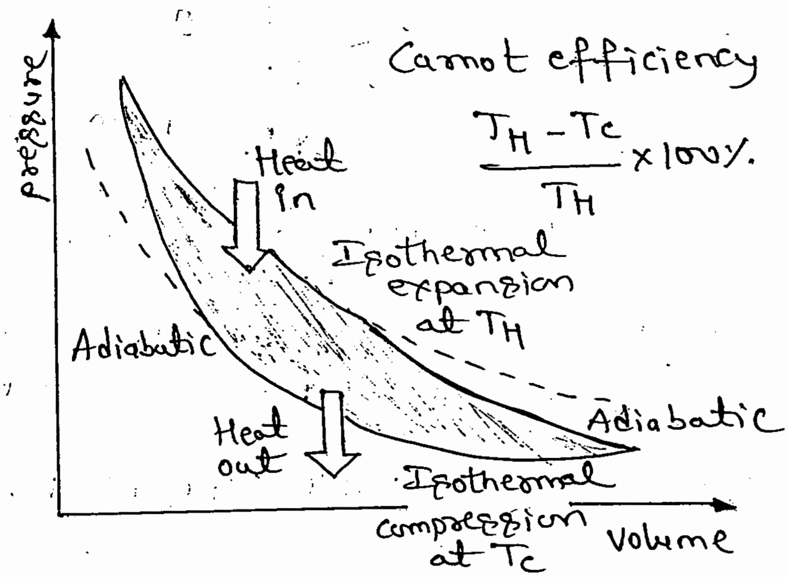

Figure 7. Carnot efficiency P-V diagram.

* The carnot cycle is the most efficient thermodynamical cycle by exploiting the warm sea surface water & cold deep sea water.

T_C be the absolute temperature of the sea surface

T_H be the absolute temperature of the deep sea water hot reservoir.

Carnot efficiency (η) is given by the following equation,

$$\eta = \frac{W}{Q_H} = 1 - \frac{T_C}{T_H}$$

VII. Application of OTEC in addition to produce electricity.

1. Electricity :- Electrical energy is the primary product of OTEC plants.
2. Hydrogen production : Electricity produced from OTEC plants is used for separating water in hydrogen & oxygen by the method of electrolysis of water.
3. Ammonia & methanol production: OTEC electricity can be used to obtain by-products, such as ammonia & 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 & hybrid-type OTEC plants through surface condenser. It is freshwater & widely used as water resource for drinking, agriculture & 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:- Cold deep sea water flowing through underground pipes chills the surrounding soil.

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

VIII Advantages, Disadvantages and benefits of OTEC.

Advantages:

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

Disadvantages:

1. High cost
2. Complexity:- OTEC plants must be located where a difference of about 20°C occurs year round. Ocean depth must be available fairly close to shore-based facilities for economic operation.
3. Acceptability: For the large-scale production of electricity & other products, OTEC plants are poorly acceptable due to their high cost
4. Ecosystem damage.
5. Lower efficiency.

Benifits:- Economic & other benefits are the value of OTEC plants. These include the following.

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