# UNIT-V

## BIOMASS

Biomass is an organic matter produced by plants, both terrestrial (those grown on land) and aquatic (those grown in water) and their derivatives. It includes forest crops and residues, crops grown on energy especially for their energy content on "energy farms" and animal manure. Unlike coal, oil and natural gas, which takes millions of years to form, biomass can be considered a renewable energy source because plant life renews and add's to itself every year. It can also be considered a form of solar energy as the latter is used indirectly to grow these plants by photosynthesis.

As the word-clearly signifies; biomass means organic matter and photo-chemical approach to harness solar energy means harnessing of solar energy by photosynthesis. Solar energy is stored in the form of chemical energy. Hence,

**Solar energy-Photosynthesis- Biomass- energy generation**

## BIOMASS AVAILABILITY

Biomass resources for energy production encompass a wide spectrum of materials ranging from silviculture (forest), agriculture (field), aquaculture (fresh and sea water) and industrial and social activities that produce organic waste residues (food processing, urban refuse etc). When plants are cultivated especially for the purpose of energy, it is known as energy farming

(i) **Forests -** Forests, natural a4s well as cultivated, serve as a source of fuel wood, charcoal and producer gas. Forest waste and residues from forest-processing industries can be utilized at the mill itself. Forest resource is consumed, not just for firewood but also for sawn timber, papermaking and other industrial purposes. Some fast-growing energy intensive trees such as encalyptus, poplar, pine are specially cultivated for the purpose of energy.

Some plants produce seeds (or nuts) to yield vegetable oil on pressing. This serves as a liquid bio fuel (bio-diesel). There are two categories of oil-producing plants: (a) wild plants, e.g, jojoba (a shrub, producing nuts) and karanj (a tree generally seen on roadsides in India, produces small seeds) that take care of themselves, and (b) agricultural crops, e.g, Jatropha curcas (Ratanjyot) 'which require common agricultural techniques. There are more than 300 different species of oil-bearing trees; most of them are wild and do not require much care and effort. These plants are quite hardy, require little water, can resist severe drought and pests, can survive in hot and cold climates and can grow on most soil types.
India, the experience with a wild, oil-bearing tree, karanj (Pongamia pinnata), has been encouraging It is estimated that its plantation on 30 million hectares would

produce enough biofuel that could completely replace the current use of fossil fuels in the country

(ii) **Agricultural Residues -** Crop residues such as straw, rice husk, coconut shell, groundnut shell, sugar cane bagasse are gasified to obtain producer gas. Alternatively, these are converted to fuel pellets or briquettes and used as solid fuel.

(iii) **Energy Crops -** Certain cultivated plants produce raw material for biofuels.. The greatest potential for energy farming occurs in tropical countries, especially those with adequate rainfall and soil conditions.

- **Sugar Plants**

  - **Sugar cane** is a major raw material source for bio-ethanol. Alcohol represents only 30% of the total sugar cane energy. About 35% is available in bagasse and another 35% in leaves and tops of the sugar-cane plant.

  - **Sweet Sorghum** also supplies raw material for ethanol production, especially during off-season supply for the sugar mills.

**Sugar Beet** supplies raw material for ethanol production.

**Starch Plants**

  - **Jerusalem Artichoke** provides raw material tor bio-ethanol. It is a tubular plant and can be grown on marginal lands and relatively poor soil. It is able to withstand adverse conditions such as cold and draught conditions.

  - **Cassava** is also a tubular plant. It is seen as complementary to sugarcane as it can be cultivated in areas with acidic infertile soils, whereas cane requires more amenable soil. It also provides raw material (starch) for bio-ethanol. Potatoes and Sweer potatoes also tall in the same category.

  - **Grains,** such as maize, barley, rice and wheat provide starch, which can be converted to ethanol.

- **Oil producing Plants**
  In a short-term diesel engine test, over 40 different plant-derived oils have been evaluated including sunflower, rapeseed, palm oil, castor oil, soybean, groundnut and cottonseed. The benefits to be derived from a plant-oil fuel industry are the following

  - Most of these plants are very adaptable and hardy.

- Because of the relatively simple technology involved in oil extraction and filtering, the oil can be produced right on the farm.
- The leftover biomass after the extraction of oil, known as cake, can be used to produce biogas in a biogas plant and the sludge produced thereof can be used as a quality fertilizer.
- The by-products from the oil press can often be used as a high-protein animal feed.
- Most of these plants require low cost and low input.
- Plant oils are safe to handle and store.
- Marginal lands and wasteland can be used for cultivation.
- It will increase the employment opportunities in rural areas and boost the economy.

**(iv) Aquatic Plants-** Some water plants grow faster than land-based plants and provide raw materials for producing biogas or ethanol. These are water byacinth, raip, seaweed and algae.

**(V) Urban Waste** Urban waste is of two types: (a) Municipal Solid Waste (MSW or garbage), and (b) sewage (liquid waste). Energy from MSW can be obtained from direct combustion (incineration) or as a landfill gas. Sewage can be used to produce biogas after some processing

## BIOMASS CONVERSION TECHNOLOGIES

There are many different ways of extracting energy from biomass. These energy-conversion technologies may be grouped into four basic types: (1) Physical method, (2) incineration (direct combustion), (3) thermo chemical method, and (4) biochemical method. The general outlines of these technologies are briefly described here**.**

### 1. Physical Method

The simplest form of physical conversion of biomass is through compression of combustible material. Its density is increased by reducing the volume by compression through the processes called briquetting and pelletization.

Fuel oils can be extracted from plant products by expelling them. Also, light hydrocarbons may be obtained from certain plants in the same way as production of rubber.

(i) **Pelletizaton-** Pelletization is a process in which waste wood is pulverized and dried forced under pressure through an extrusion device The extracted mass is in the form of pellets (rod, 5 to 10 mm dia and 12 mm long, facilitating its use in steam power plants and gastification system. Pelletization reduces the moisture to about 7 to 10 per cent and increases the heat value of the biomass.

(ii) **Briquettng** Biomass briquettes are made from woody matter (e.g. agricultural waste and saw dust), are a replacement for fossil fuels such as oil or coal and can be used to heat boilers in manufacturing plants. Burning a wood briquette is far more efficient than burning firewood. The moisture content of a briquette can be as low as 4%, whereas for green firewood, it may be as high as 65%.

Briquetting is brought about by compression and squeezing out moisture and breaking down the elasticity of the wood and bark. If elasticity is not sufficiently removed, the compressed wood will regain its pre-compression volume. Densification is carried out by compression under a die at high temperature and pressure. It is a process similar to forming a wood pellet but on a larger scale. There are no binders involved in this process. The natural lignin in the wood binds the particles of wood together to form a solid piece.

Sawdust briquettes have developed over time with two distinct types: those with holes through the centre, and those which are solid. A solid briquette is manufactured using a piston press which simply sandwiches layers of sawdust together, and ones which have a hole are produced using a screw press. The hole is simply a by-product of the screw thread passing through the centre. The screw – press briquettes are more homogeneous, have better crushing strength and better storage properties with extraordinary combustion properties due to large surface area per unit weight.

(iii) **Expelling Agro Products** Concentrated vegetable oils may be obtained from certain agro products and may be used in diesel engines. However, difficulties arise with direct use or plant oil due to high viscosity and combustion deposits. Therefore, these oils are upgraded by a chemical method known as transesterification to overcome these difficulties. Categories of certain materials with examples are as follows:

- Seeds Sunflower, rapeseed, soya beans
- Nut Oil palm, coconut copra, Jojoba nuts
- Fruits Olive
- Leaves Eucalyptus

(iv) **Fuel Extraction** Occasionally, milky latex is obtained trom freshly cut plants. The material is called excudates and is obtained by cutting (tapping) the stems or trunks of living plants (a technique similar plants (a technique similar to that used in rubber production). Some plants are not amenable to tapping and in such cases, the whole plant (usually a shrub) is crushed to obtain the product. For example, the Euphorbia lathyris plant is crushed to extract hydrocarbons of less molecular weight than rubber, which may be used as a petroleum substitute.

2. **Incineration**

   **Incineration** means direct combustion of biomass for immediate useful heat. The heat and/or steam produced are either used to generate electricity or provide the heat for industrial process, space heating, cooking or district heating.

   Furnaces and boilers have been developed for large-scale burning of various types of biomass such as wood, waste wood, black liquid from pulp industry, food industry waste, and MSW. The moisture content in the biomass and wide range of composition tends to decrease the efficiency of conversion. However, the economic advantage of Cogeneration makes it attractive for adoption.

**3. Thermochemical**

The basic thermochemical process to convert biomass into a more valuable and or convenient product is known as pyrolysis. Biomass is heated either in absence of oxygen or partial combustion of some of the biomass in restricted air or oxygen supply. Pyrolysis can process all forms of organic materials including rubber and plastics, which cannot be handled by other methods. The products are three types of fuels- usually, a gas mixture (H2, CO, CO2, CH4, and N2), an oil-like liquid (a water-soluble phase including acetic acid, acetone, methanol and a non-aqueous phase including oil and tar) and a nearly pure carbon char. The distribution of these products depends upon the type of feedstock, the temperature and pressure during the process and its duration and the heating rate.

High temperature Pyrolysis (1000 degree celcius) maximizes the gaseous product. The process is known as gasification. Low temperature pyrolysis (up to 600) maximizes the char output. The process has been used for centuries for production of charcoal. The process is known as carbonization. A liquid product is obtained through catalytic liquefaction process. Liquefaction is a relatively low temperature (250-450 degree celcius), high-pressure (270 atm) thermochemical conversion of wet biomass, usually with high hydrogen partial pressure and also a catalyst to enhance the rate of reaction and/or to improve the selectivity of the process.

**4. Biochemical**

The process makes use of metabolic action of microbial organisms on biomass to produce liquid and gaseous fuel. Two major biochemical processes are explained below:

**(a) Ethanol Fermentation** Alcoholic fermentation is the decomposition in the absence of air of simple hexose sugars (sugars containing six carbon atoms per molecule, i.e., $C_6H_{12}O_6$) in aqueous solution by the action of an enzyme (a natural catalyst) present in yeast, in acidic conditions ($p^H$ value of 4 to 5). Thus,

$$C_6H_{12}O_6 \xrightarrow[\text{Fermentation}]{32^\circ C} 2C_2H_5OH + 2CO_2$$

The products are ethanol and carbon dioxide.

(b) **Anaerobic Fermentation (Anaerobic Digestion)** This process converts decaying wet biomass and animal wastes into biogas through the decomposition process by the action of anaerobic bacteria (bacteria that live and grow in absence of oxygen). Carbon present in biomass may be ultimately divided between fully oxidized $CO_2$, and fully reduced $CH_4$. Thus,

$$\text{Decaying wet biomass} \xrightarrow[\text{Anaerobic Fermentation}]{20-55\ ^\circ C} \text{Biogas (largely } CH_4 \text{ and } CO_2)$$

The biomass material in the form of water slurry is digested by the bacteria anaerobically for several days in an airtight container. The reactions are slightly exothermic and a small amount of heat (equivalent to 1.5 MJ per kg dry digestible material) is also generated that helps in maintaining a favourable temperature. The process may be expedited at somewhat higher temperature. The most useful biomass materials appear to be animal manure, algae, kelp, hyacinth, plant residues and other organic waste materials with high moisture content. The energy available from various biomass resources is listed below,

**Energy available from various biomass resources**

| *SN* | *Biomass source* | *Biofuel produced* | *Conversion technology* | *Available energy (MJ/kg)* |
|---|---|---|---|---|
| 1. | Wood chips, saw mill dust, forest residues | (Direct heat) | Incineration | 16–20 |
| 2. | Wood chips, saw mill dust, forest residues | Gas<br>Oil<br>Char | Pyrolysis | 40 (Nitrogen removed)<br>40<br>20 |
| 3. | Grain crops | Straw | Incineration | 14–16 |
| 4. | Sugar-cane residue | Bagasse | Incineration | 5–8 (fresh cane) |
| 5. | Urban refuse | (Direct heat) | Incineration | 5–16 (dry input) |
| 6. | Sugar-cane juice | Ethanol | Fermentation | 3–6 (fresh cane) |
| 7. | Animal waste | Biogas | Anaerobic digestion | 4–8 (dry input) |
| 8. | Municipal sewage | Biogas | Anaerobic digestion | 2–4 (dry input) |

## OCEAN THERMAL ENERGY CONVERSION

Ocean Thermal Energy Conversion Plants (OTEC) converts thermal energy from ocean water to electrical power. OTEC cogeneration plants deliver electrical energy and fresh water. The plants are built either on shore or on high seas.

OTEC Technology is in infant stage. Conceptual designs of open cycle OTEC plants and closed cycle OTEC plants have been finalised. The unit size of turbine generators is in the range of 10 MW to 50 MW. The plant ratings are of 50 MW and 100 MW.

OTEC plants have several limitations and techno-economic constraints. Hence, their commercial prospects are quite uncertain.

Because of the problems associated with large stationary, OTEC Plants, the concept of Small OTEC Ship Plants is under consideration. The entire OTEC plant will be installed on a ship. The ship will move slowly (0.5 knots) to the location of warm surface water.

-Electric energy generated in the OTEC ship Plant will be used on the board of the ship itself for
-Extracting and converting biomass energy into methane, hydrogen etc.

Chemical and metallurgical production based on ocean water (1odine, ammonia, magnesium, nickel, uranium etc.) OTEC technologies are costly and difficult. OTBC projects are being financed by various authorities such as Department of Non-Conventional and Renewable Energy.

**Principle of OTEC**

The ocean water gets heated up naturally due to solar radiation. The temperature of water near surface is higher than that of deep water. Significant amount of heat can be extracted from by Ocean Thermal Gradient Principle of thermodynamics.

A heat engine can operated between two temperatures, $T_1$ and $T_2$. In case of OTEC:

- **Source temperature ($T_1$):** Temperature of warm surface water of ocean
- **Sink temperature ($T_2$)** : Temperature or cold deep water of ocean.

Maximum theoretical efficiency of a heat engine operation between source temperature ($T_1$) and sink temperature ($T_2$) is called Carnot Efficiency ($\eta_c$) and is given by

$$\eta_c = (T_1 - T_2) / T_1$$

T1 and T2 are in absolute temperature expressed in Kelvin (K) = (0°C + 273). It is desirable to have temperature difference ($T_1$-$T_2$) so as to have higher efficiency.

The average **Surface Water Temperatures** ($T_1$) for tropical ocean water are in the range of 24°C and 27°C.

**Deep Water Temperatures** (T2) are lower than surface water temperature with a temperature difference of about 4°C to 6°C per km depth. The temperature gradient is non-uniform.

Temperature difference ($T_1$-$T_2$) of 20°C can be obtained from Ocean Thermal Gradient (corresponding to 500°C temperature difference in fossil fuel combustion thermal plants). Assuming temperature difference of OTEC as 20°C.

$$\eta_c = 20/\ (27+273) = 0.0667 = 6.67\%$$

Thus, for maximum surface water temperature of 27 °C and Temperature difference ΔT, the Carnot efficiency of an OTEC System could be

$$\begin{aligned} \eta_c &= (T_1-T_2)/T_1 \\ &= \Delta T\ /(27+273) \\ &= \Delta T/\ 300 \end{aligned}$$

$$\%\ \ \eta_c = (\Delta T/300)\ {*}100\%$$

**where** ΔT is difference in temperature between surface water and deep water.

The Actual efficiency of a Practical OTEC Plant is less than 2 percent.

**Two types of OTEC system under active consideration are**,

**1. Open Cycle (Claude cycle, steam cycle)**
In Open Cycle, the warm ocean water is converted into, steam into an evaporator. The steam drives steam-turbine generator to deliver electrical energy.

**2. Closed Cycle (Anderson Cycle, Vapour Cycle)**

In Closed Cycle, the ocean thermal energy is given to liquid working fluid (Ammonia, butane or freon). Vapour of the working fluid drives vapour turbine generator to deliver electrical energy.

**Cogeneration OTEC Plants** deliver electrical energy and fresh water.

**Ocean Surface Temperature (T)**
Ocean water gets warmed up naturally due to solar radiation higher temperature at surface. Solar radiation at a particular depends on latitude and season. Likewise, average surface temperature of ocean is higher in tropical zones and during summers than in arctic zones and during winters. Fig.1 and Fig.2 illustrates the variation of ocean surface water temperatures with latitude and season.

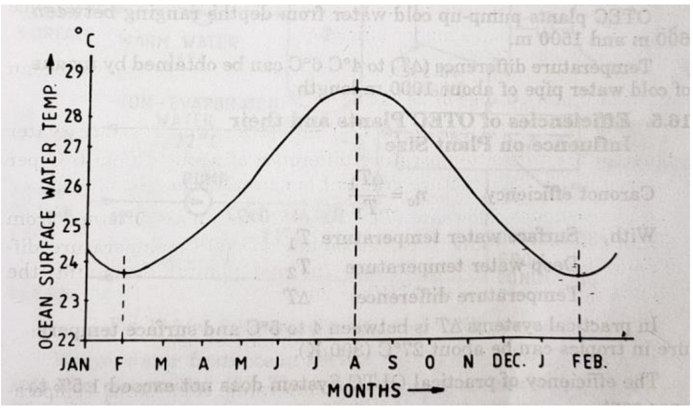

Fig. 1 Monthly variation of surface temperature of tropical ocean water

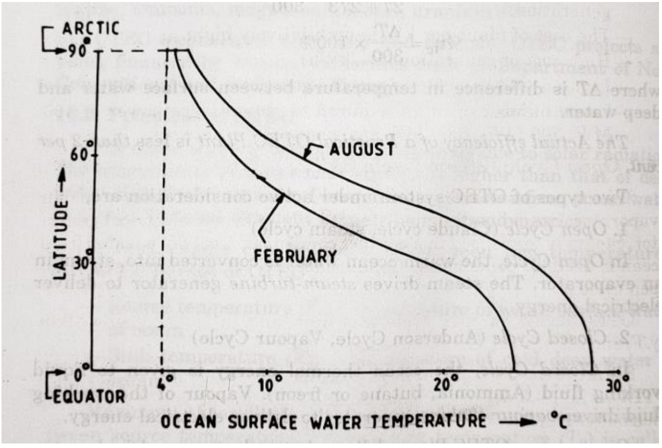


Fig. 2 Variation of surface temperature of tropical ocean water with season and latitude

## Deep Water Temperature

The temperature of ocean water reduces at a gradient of 4 °C per km depth. The gradient is non-uniform. OTEC plants pump-up cold water from depths ranging between 600 m and 1500 m.

Temperature difference (ΔT) to 4°C 6°C can be obtained by means of cold water pipe of about 1000 m length.

## Efficiencies of OTEC Plants and their Influence on Plant Size

Carnot efficiency $\boldsymbol{\eta_c = \Delta T_1 / T_1}$

With, Surface water temperature $T_1$
Deep water temperature $T_2$
Temperature difference $\Delta T$

In practical systems ΔT is between 4° to 5°C and surface temperature in tropics can be about 27°C (300 K).
The efficiency of practical OLTC System does not exceed 1.5% to per cent.

**Due to low efficiency, the OTEC plants should have**

-Large intake of warm water requiring large pipe line, pumps, heat exchanger, larger size of power plant per kW rated generation.
-The cost of plant per kW is prohibitively high.
-High cost of generation (Rs./kWh)
-Limited unit capacity of turbine generator unit (25 kW).
-Large number of units required to obtain large power of 100 MW, 500 MW, 1000 MW etc. required for network.

**1.Open Cycle (Steam Cycle OLTC)**

Warm ocean water is converted into flashed steam in an evaporator. Specially designed steam turbine drives electrical generator. Steam is condensed in a contact condenser.

Cool deep water from ocean is used for condensing. Condensate is discharged into sea in an open cycle.

OTEC based on open cycle was first built in Cuba during 1929 by French Engineer George Claude.

**Schematic and Thermodynamic Cycle for Open Cycle OTEC**
Fig. 3 (a) is a schematic and Pig.3 (b) is corresponding thermodynamic cycle on Temperature (T)/Entropy (S) plane.

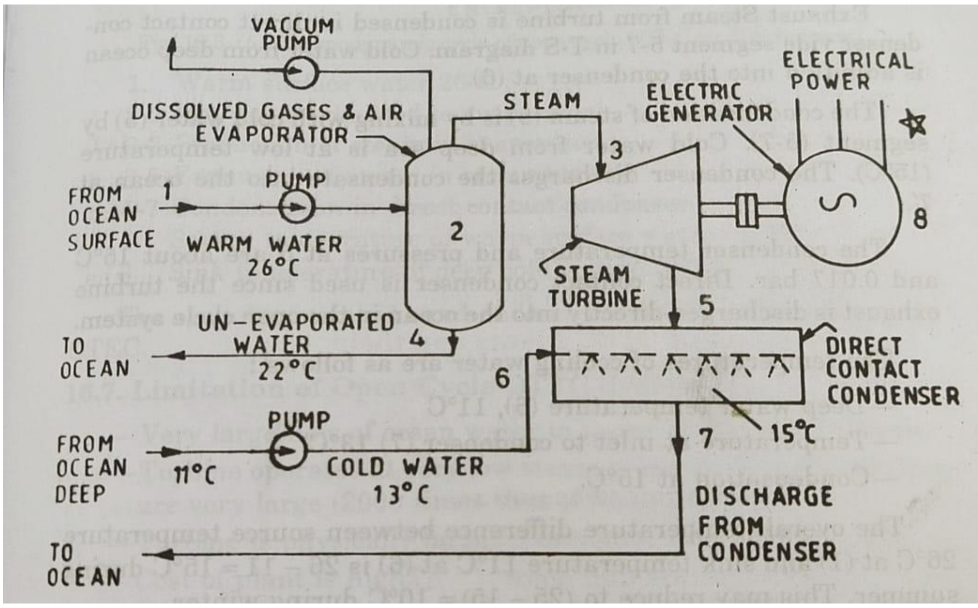

Fig. 3 (a) Schematic of an ocean cycle OTEC power plant

Warm water from ocean surface (1) (at about 26°C) is admitted into the evaporator (2). The evaporator is maintained at vacuum pressure by means of vacuum pump. At low vacuum pressures, the boiling point of water reduces and more steam is generated. (Segment 1-2 in T/S diagram). The saturated steam generated in evaporator (at 2) is admitted into a special steam turbine water is converted into saturated steam (by segment 2-3 in T/S Diagram). Remaining water from evaporator is discharged into the sea at (4) (Segment 2-4 in T-S Diagram).

Steam-turbine converts thermal energy into mechanical energy as the steam expands in turbine buckets (rotor blades) Segment (3-5) on T-S diagram represent expansion of steam in the steam turbine.

Steam at (3) is comparatively at low pressure, and high specific volumes as compared with conventional steam power plants.

**Comparison of Open OTEC and Conventional Steam Turbine Plant**

| Open Cycle OTECL | | Conventional Steam-Turbine Power Plants |
|---|---|---|
| Steam inlet pressure | – 0.0317 bar | 160 bar |
| Steam specific volume | 43 $m^3/kg$ | 0.021 $m^3/kg$ |
| Temperature | 25°C | 500°C |

Exhaust Steam from turbine is condensed in direct contact condenser vide segment 5-7 in T-S diagram. Cold water from deep ocean is admitted into the condenser at (6).

The condensation of steam (5) 1s by mixing with cold water (5) by segment (5-7). Cold water from deep sea is at low temperature (15°C). The condenser discharges the condensate into the ocean at 7'.

The condenser temperature and pressure at 5 are about 15°C and 0.017 bar. Direct contact condenser 1s used since the turbine exhaust is discharged directly into the ocean in the open cycle system.

**The temperatures of cooling water are as follows:**

-Deep water temperature (6), 11°C
-Temperature at inlet to condenser (7) 13°C
-Condensation at 15°C.

The overall temperature difference between source temperature 26°C at (1) and sink temperature 11°C at (6) is 26-1l=15 °C during summer. This may reduce to (25- 15) = 10°C during winter.

The steam admitted in steam turbine (3) drives the steam turbine rotor and is exhausted (5) in condenser. Segment (3-5) in the T-S plane represents the expansion of steam in the condenser. Due to very low differences in source and sink temperatures, efficiency is very low. Heat loss from external surfaces of pipe lines, condenser, turbines should be minimized to absolute minimum. Pumps should be very efficient.

**Summary of Thermodynamic Cycle Segments** Fig. 3 (b) has following segments

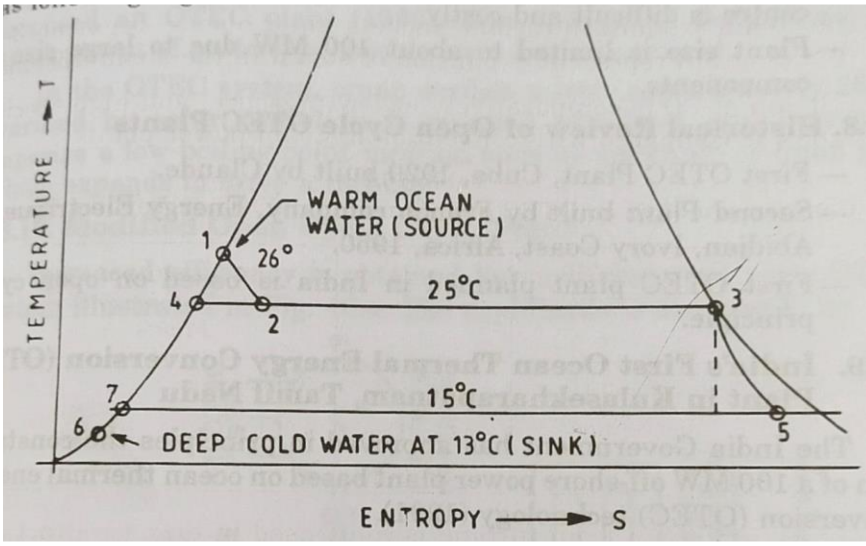


Fig. 3 (b) Thermodynamics cycle of open cycle OTEC on T-S diagram

1. Warm surface water 26°C
   1-2 Hot water admitted to evaporator.
   2-3 Production of steam in evaporator.
   3-5 Expansion of steam in steam-turbine
   5-7 Condensation in direct contact condenser.
   1 Source temperature of warm surtface water: 26°C
   6 Sink temperature of deep cold water: 13°C.
   The cycle begins at (1) and ends at (6) and is called open cycle OTEC.

**Limitation of Open Cycle OTEC System**

- Very large flow of ocean water in terms of mass and volume.
- Turbine operates at very low steam pressure. Specific volumes are very large (2000 times that of fossil fuel płant)
- Turbine is physically large.
- Cost of plant is high.
- Cost of electrical energy from open cycle OTEC is very high. Hence, such plants are not economically viable at present.
- Plant is subjected to ocean storms, high waves, etc. The plant subjected to extremely severe stresses.
- Corrosion of metal parts due to saline water. Erosion of parts due to particles in flowing water.
- Algae and kelp grows in pipes and obstructs water flow
- Salts get deposited in pipes and equipment. Maintenance is difficult.
- Construction of floating power plants is difficult.
- Power transfer from off-shore OTEC plant to land based load centre is difficult and costly.
- Plant size is limited to about 100 MW due to large size of components.

## Cogeneration of Electricity and Fresh Water from Open Cycle OTEC

The controlled flash evaporator (CEF) used in the modified open cycle OTEC plant separates steam from brine. Steam received from the turbine is condensed in a surface condenser without mixing with the old ocean water. The condenser delivers fresh water with salt content of 1 to 5 ppm. Turbine generator delivers electrical power. Thus OTEC cogeneration plant utilises ocean thermal energy to deliver.

- Electrical energy and
- Fresh Water.

## 2.Closed Cycle OTEC (Anderson Cycle, Vapour Cycle)

In a closed cycle OTEC plant working fluid of low boiling point circulates in a closed cycle comprising heat exchanger, vapour turbine, surface condenser and liquid vapour pressuriser. Warm surface ocean water delivers heat to the working fluid in the heat exchanger. Cold deep ocean water extracts heat from the spent vapours in the condenser.

Working fluids used in closed cycle OTEC can be
- Ammonia ($NH_3$)
- Butane
- Freon

Fig. 4 represents the schematic of a closed cycle OTEC plant. Warm water from Ocean (1) is pumped into the heat exchanger (2) and is discharged into the ocean (3).

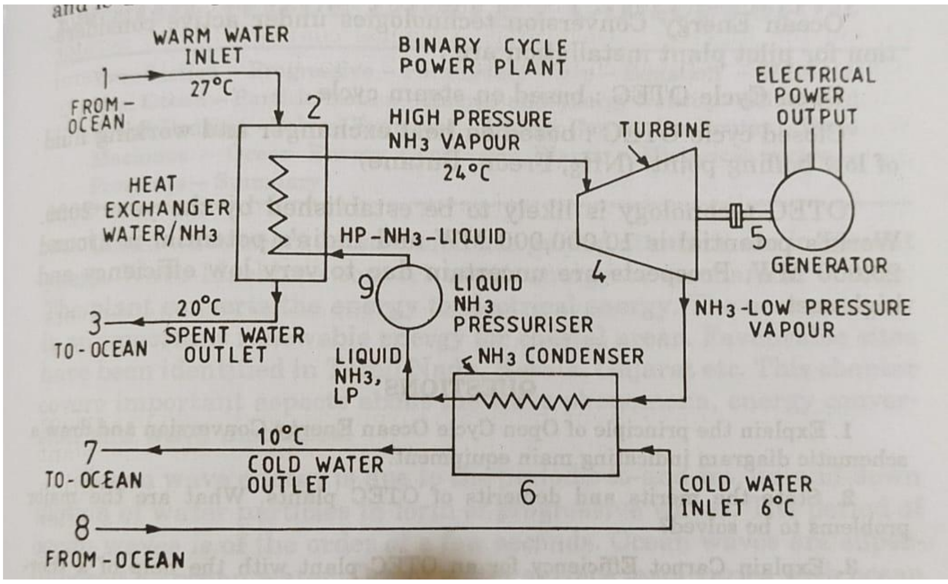

Fig. 4 Closed cycle OTEC plant schematic

Working fluid (say Ammonia, $NH_3$) is circulated through the closed cycle comprising

- Heat exchanger (3)
- Vapour condenser (6)
- Vapour turbine (4)
- Liquid pressuriser (9)

The working fluid extracts heat from the warm ocean water and is vapourised. The vapours having thermal energy are expanded in the vapour turbine (4). The thermal energy is converted to mechanical energy by turbine. The turbine drives electrical generator rotor (5). The generator produces electrical energy. The spent vapours are condensed in condenser which utilises cold water from deep sea as a coolant. Liquified working fluid is passed through pressuriser (9) into the heat exchanger (2). The working fluids is cireulated again and again through the closed cycle.

The closed cycle OTEC concept was proposed by Barjot in 1926. Tne concept was further developed by Anderson in 1992. Anderson proposed propare as working fluid with T= 20°C between Warm surface sea water (Source) and C Cold sea water (sink)

Propane vapourises in heat exchanger at 10 bar and is exhanet from turbine at 5 bar. The closed cycle OTEC plant works on closed Rankine thermodynamic cycle. A proposed OTEC plant has four turbine-generator units of 25 MW each, with a central vertical pipe of 1400 m depth for cold water.

**Summary**

Ocean Energy Conversion technologies under active consideration for pilot plant installation are:

- **Open Cycle OTEC:** based on steam cycle
- **Closed cycle OTEC**: based on heat exchanger and working fluid of low boiling point. ($NH_3$, Freon, Butane)

OTEC technology is likely to be established by the year 2000. World's potential is 10,000,000 MW and India's potential and is around 20,000 MW. Prospects are uncertain due to very low efficiency & high cost.

## WAVE ENERGY

Waves form as wind blows over the surface of open water in oceans and lakes. Ocean waves contain tremendous energy. The advantages of wave energy include being free, sustainable, renewable, and producing zero waste. Therefore, it can contribute to reducing our carbon footprint. It is also unique since it is the most concentrated form of renewable energy on earth, with power density much higher than that of wind and solar energy.

Wave energy, also known as ocean energy or sea wave energy, is a form of energy harnessed from the ocean or sea waves. The rigorous vertical motion of surface ocean waves contains a lot of kinetic (motion) energy that is captured by wave energy technologies to do useful tasks.

The wave energy captured is used for all different kinds of useful work, including electricity generation, desalinization of water, and pumping of water into reservoirs.
What is wave energy used for?
The wave energy captured is used for all different kinds of useful work, including electricity generation, desalinization of water, and pumping of water into reservoirs.

**How does wave energy work?**
Wave power is produced by the up and down motion of floating devices placed on the surface of the ocean. In other words, wind produces waves, and then waves produce energy. As the waves travel across the ocean, high-tech devices capture the natural movements of ocean currents and the flow of swells to generate power.

**What is wave energy converter?**
Wave energy converters (WECs) are devices that convert the kinetic and potential energy associated with a moving ocean wave into useful mechanical or electrical energy. This energy is the largest estimated global resource form of ocean energy.

**Different types of wave energy converters**

- Attenuators
- Point Absorbers
- Oscillating wave surge converter
- Oscillation water column
- Overtopping/terminator device
- Submerged pressure differential
- Bulge wave
- Rotating mass

**Attenuators**
An attenuator is a floating device that operates parallel to the wave direction and effectively rides the waves. These devices capture energy from the relative motion of the two arms as the wave passes them.

**Point Absorbers**
A point absorber is a floating structure that absorbs energy from all directions through its movements at/near the water surface. It converts the motion of the buoyant top relative to the base into electrical power. The power take-off system may take several forms, depending on the configuration of displacers/reactors.

**Oscillating wave surge converter**
Oscillating wave surge converters extract energy from wave surges and the movement of water particles within them. The arm oscillates as a pendulum mounted on a pivoted joint in response to the movement of water in the waves.

**Oscillation water column**
An oscillating water column is a partially submerged, hollow structure. It is open to the sea below the waterline, enclosing a column of air on top of a column of water. Waves cause the water column to rise and fall, which in turn compresses and decompresses the air column. This trapped air is allowed to flow to and from the atmosphere via a turbine, which usually can rotate regardless of the direction of the airflow. The rotation of the turbine is used to generate electricity.

**Overtopping/terminator device**
Overtopping devices capture water as waves break into a storage reservoir. The water is then returned to the sea passing through a conventional low-head turbine which generates power. An overtopping device may use 'collectors' to concentrate the wave energy.

**Submerged pressure differential**
Submerged pressure differential devices are typically located near shore and attached to the seabed. The motion of the waves causes the sea level to rise and fall above the device, inducing a pressure differential in the device. The alternating pressure pumps fluid through a system to generate electricity.

**Bulge wave**
Bulge wave technology consists of a rubber tube filled with water, moored to the seabed heading into the waves. The water enters through the stern and the passing wave causes pressure variations along the length of the tube, creating a 'bulge'. As the bulge travels through the tube it grows, gathering energy that can be used to drive a standard low-head turbine located at the bow, where the water then returns to the sea.

**Rotating mass**
Two forms of rotation are used to capture energy by the movement of the device heaving and swaying in the waves. This motion drives either an eccentric weight or a gyroscope causes precession. In both cases, the movement is attached to an electric generator inside the device.

**Other**
This covers those devices with a unique and very different design to the more well-established types of technology or if the information on the device's characteristics could not be determined. For example, the Wave Rotor is a form of turbine turned directly by the waves. Flexible structures have also been suggested, whereby a structure that changes shape/volume is part of the power take-off system.

### 9.4.3. Energy and Power from the Waves

A two dimensional progressive wave as shown in Fig. (9.15), is represented by the sinusoidal simple harmonic wave shown at time $t = 0$, and at time $t$. The wave may be expressed by the following relation involving some parameters:

$$y = a \sin\left(\frac{2\pi}{\lambda} x - \frac{2\pi}{\tau} t\right) \quad ...(9.14)$$

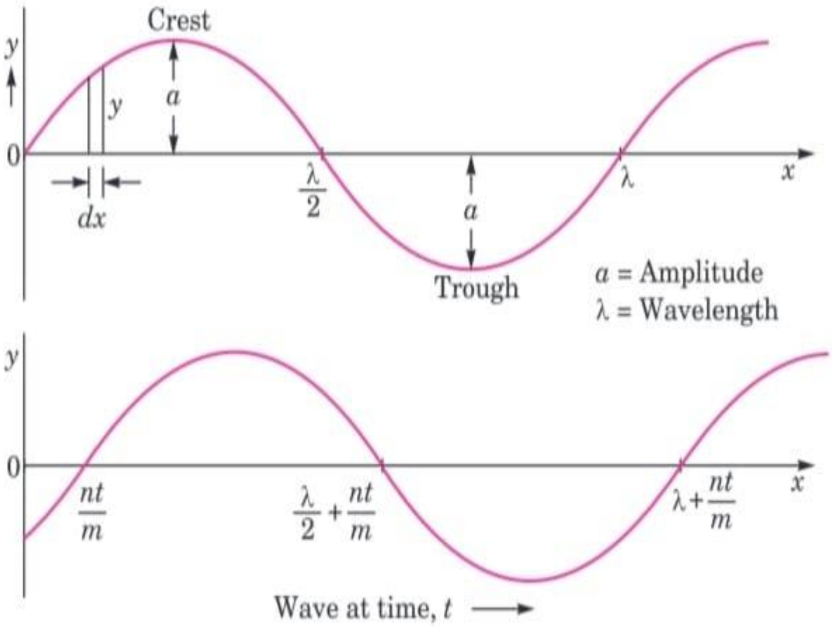


Fig. 9.15. A typical progressive wave.

where, $y$ = height above its mean level in m. $\quad a$ = amplitude in m

$\lambda$ = wave length in m $\quad t$ = time in seconds

$\tau$ = period in seconds

$$2\pi = \left(\frac{x}{\lambda} - \frac{t}{\tau}\right) = \text{phase angle (dimensionless)}$$

The relationship between wavelength and period is approximately

$$\lambda = 1.56\ \tau^2 \quad ...(9.15)$$

The expression (9.14) can be expressed as

$$y = a \sin(mx - n\,t) \quad ...(9.16)$$

where, $m = \dfrac{2\pi}{\lambda}$ and $n = \dfrac{2\pi}{\tau}$ = phase rate

$2a$ = height (from crest to trough).

**Potential Energy.** The potential energy arises from the elevation of water above mean level (*i.e.*, $y = o$) considering a differential volume $y \cdot dx$, it will have a mean height $\lambda/2$. Thus its potential energy is

$$dPE = m\,g\,y/2 = (\rho\,y\,dx\,L)\,g\,y/2$$

$$g\rho y^2\,L\,dx$$

where, $m$ = mass of the liquid in $y \cdot dx$, kg

$g$ = gravitational constant

$\rho$ = water density, kg/m$^3$,

$L$ = arbitrary width of the two dimensional wave, perpendicular to the direction or wave propagation $x$, $m$.

Combining (9.16) and (9.17), we obtain:

$$PE = \frac{\rho L a^2 g}{2} \int_0^{\lambda} \sin^2 (mx - nt)\, dx \qquad ...(9.18)$$

$$= \frac{\rho L a^2 g}{2} \left( \frac{1}{2} mx - \frac{1}{4} \sin 2\, mx \right)_0^{\lambda}$$

$$= \frac{1}{4} g \rho a^2 \lambda L \qquad ...(9.19)$$

The potential energy density per unit area is $PE/A$, where, $A = \lambda L$, in $J/m^2$.

$$\therefore \qquad \frac{PE}{A} = \frac{1}{4} g \rho a^2 \qquad ...(9.20)$$

**Kinetic Energy.** The derivation of the K.E. is rather complex and beyond the scope of the book. From hydrodynamic theory this can be expressed as

$$\text{K.E.} = \frac{1}{4} g \rho a^2 \lambda L \qquad ...(9.21)$$

and the K.E. density is

$$\frac{\text{K.E.}}{A} = \frac{1}{4} g \rho a^2 \qquad ...(9.22)$$

Total energy and power density can be written as

$$\frac{E}{A} = \frac{1}{2} g \rho a^2 \qquad ...(9.23)$$

$$\frac{P}{A} = \frac{1}{2} g \rho a^2 . f$$



where, $f$ is the frequency. (The Power $P$ = energy × frequency).

## Advantages of Wave Energy

- The wave energy has the advantage over wind or solar that the energy has been naturally concentrated by accumulation overtime and space and transported from the point at which it was originally present in the winds.

- The degree of power concentration effected by waves is quite substantial whereas the power density in wind may, at a good site, average some hundreds of watts per square meter; wave from being transported across a plane perpendicular to the wave propagation direction at a good site is from 10 to 100 times at large.

- It is a free and renewable energy source.

- Wave power devices do not use up large land masses unlike solar or wind.

- These devices are relatively pollution free because they remove energy from waves; leave the water in relatively placid (calm) states in their wakes.

## Disadvantages of Wave Energy

- The major disadvantage of wave energy, as compared to wind, is that the energy is available on the ocean. The extraction equipment must operated in a marine environment with all that implies in terms of maintenance, construction, cost, life time, and reliability. The energy may have to be transported a greater distance to shore.

- Wave, energy converters must be capable of withstanding very severe peak stresses in storms.

- There is relatively scarcity of accessible sites of large wave activity.

- Wave energy conversion devices that have been proposed are relatively complicated.

## Environmental Impacts

Wave power is essentially non-polluting. No appreciable environmental effects are foreseen from isolated floating wave power devices. However, onshore wave energy installations may change visual landscape and degrade scenic Ocean front views. It may also cause disturbance to marine life including changes in distribution and types of life near the shore, and possible threat to navigation from collision due to low-profile floating wave devices. It would usually be both possible and necessary to avoid hazards to or from marine traffic by judicious sitting and by provision of navigation aids.

## TIDAL ENERGY

Tidal energy exploits the natural rise and fall of coastal tidal waters caused principally by the interaction of the gravitational fields of the sun and the moon. The ocean level difference caused due to tides contains large amount of potential energy. The highest level of tidal water is known as flood tide or high tide.
The lowest level is known as low tide or ebb. The level difference between the high and low tide is known as tidal range. The tidal range varies greatly with location. Only sites with large tidal ranges (about 5 m or more) are considered suitable for power generation. The total combined potential at these sites is estimated as 1,20,000 MW.

The principle used for harnessing this energy consisted of a pond filled through sluice (rapid controlled gates) when tides are high and emptying it during low tides via an undershot waterwheel, producing mechanical power. Even now, the same basic principle with improvements in the design, material and operation techniques is being used to generate electricity in the same manner as in a hydroelectric plant.

### Origin and Nature of Tidal Energy

Tides are produced by the gravitational attraction of the moon and the sun acting upon the rotating earth. The moon exerts a larger gravitational force (about 70 percent of the tide-producing force) on the earth, as it is a great deal closer than the sun. Surface water is pulled away from the earth on the side facing the moon, and at the same time the solid earth is pulled away from the water on the opposite side. Thus the ocean height increases at both the near and far sides of the earth as shown in Fig 5. The solid earth rotates with a period of one day underneath these two bulges. These bulges are swept westward, due to the earth s rotation, as deep ocean waves lasting a period 12 hours and 25 minutes. The sun's effect is similar but smaller in magnitude (about 2.2 times less than lunar), and with a period of 12 hours. These are thus semi-diurnal changes of ocean level. Due to sight difference of periods, the solar tide moves in and out of phase with the lunar tide. When the sun, earth and moon are aligned (approximately) in conjunction, the lunar and solar tides are in phase, producing net tides of maximum range. These are the spring tides occurring twice per lunar month at times of both full and new moon. When sun-earth and moon-earth directions are perpendicular (in quadrature), the solar and lunar tides are out of phase producing net tides of minimum range. These are the neap tides that again occur twice per month at times of half moon (first and third quarter cycle of the moon) as shown in Fig. 6

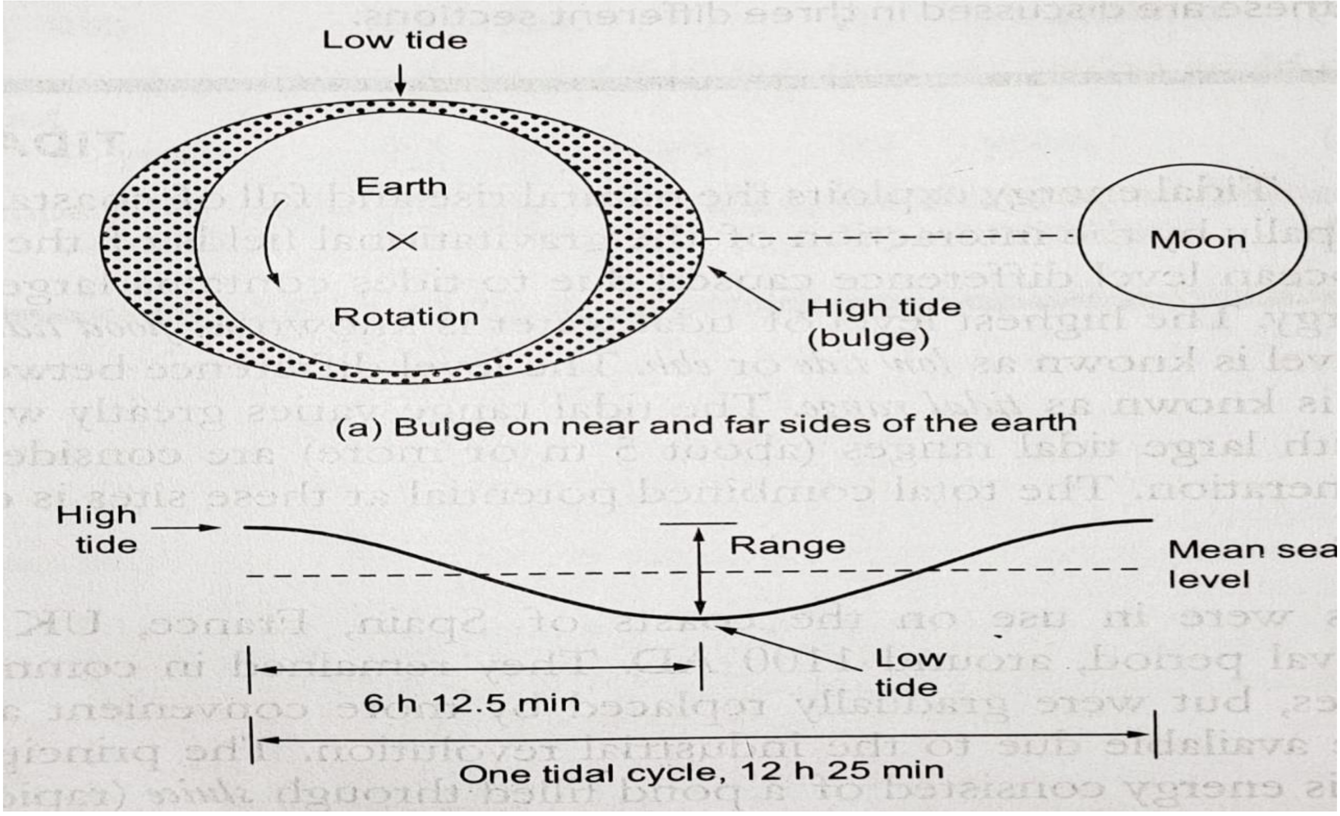


**Fig. 5 Origin of Tides**

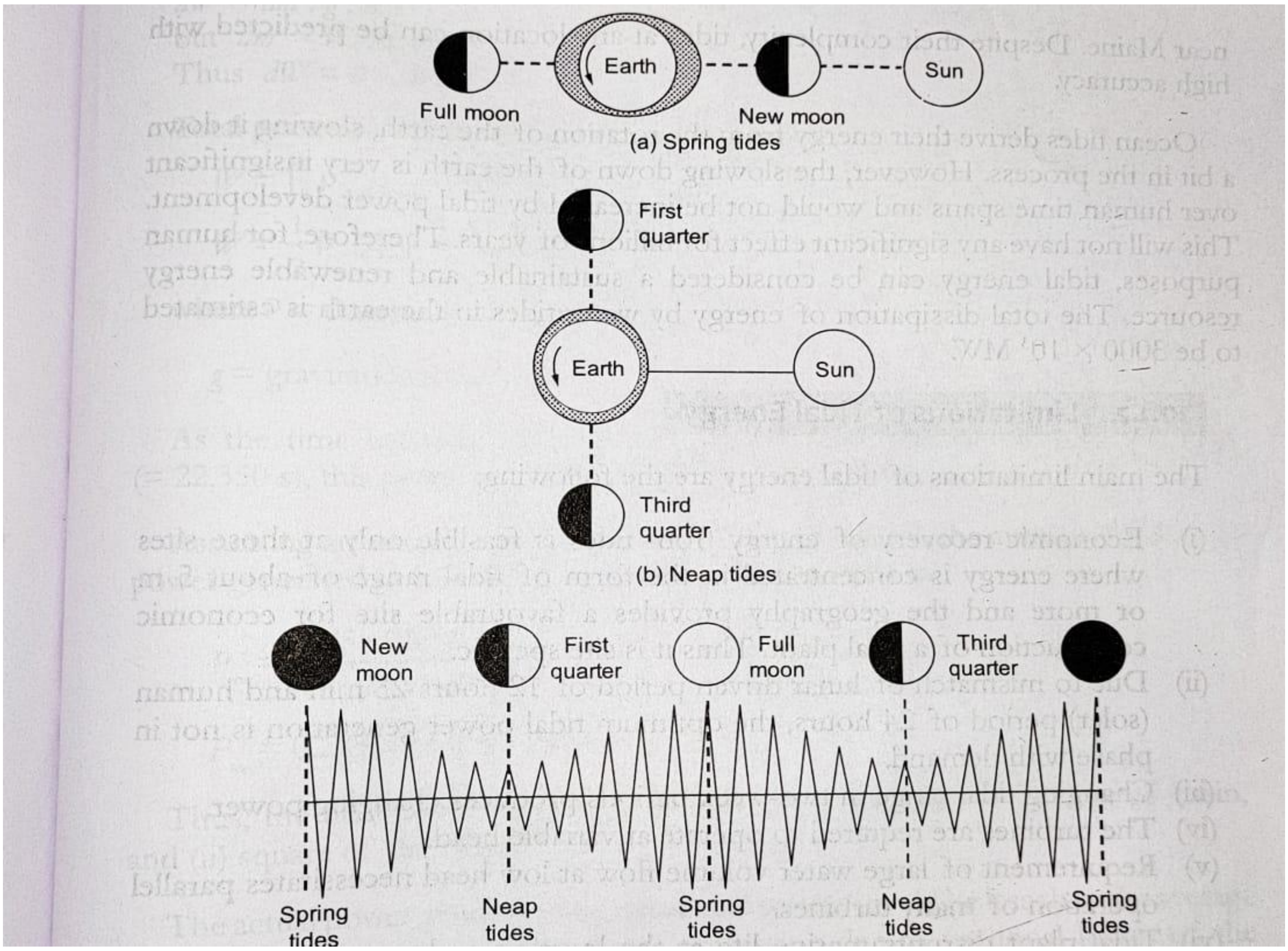


**Fig. 6 Nature of Tides**

Superimposed on these short-term variations caused by the sun-moon system, there are many other cycles of small magnitudes with periods ranging from days to years. For example, (i) long-term (yearly) variations arise from the changes in the distance of the earth from the sun during a year, (ii) variations as the moon-earth distance oscillates slightly in a period of 27.55 solar days, (iii) variations as the moon's plane of motion moves about 2 degree in and out of the earth-sun ecliptic plane, and also (iv) other variation cycles that last for many years, arising out of complex interactions between the gravitational fields.

In open oceans, tidal ranges are commonly of the order of 0.6 m to 0.9m. However, when the Ocean tidal waves impinge on continental shelves and coastlines, their ranges can amplify substantially through (i) run-up, (ii) funneling, and (iii) resonance, depending on the nature of the coastline. Thus, tidal range varies from place to place. In some places such as shallow bays and estuaries, the amplification 15 considerable. Exceptionally high tides with a tidal range of about 11 m (or more) occur in the Bay of Fundy on the Atlantic coast of Canada near Maine. Despite their complexity, tides at any location can be predicted with high accuracy.

Ocean tides derive their energy from the rotation of the earth, slowing it down a bit in the process. However, the slowing down of the earth is very insignificant over human time spans and would not be increased by tidal power development. This will not have any significant effect for billions of years. Therefore, for human purposes, tidal energy can be considered a sustainable and renewable energy resource. The total dissipation of energy by water tides in the earth is estimated to be 3000 x $10^3$MW.

**Limitations of Tidal Energy**

**The main limitations of tidal energy are the following,**

- Economic recovery of energy from tides is feasible only at those sites where energy is concentrated in the form of tidal range of about 5 m or more and the geography provides a favorable site tor economic construction of a tidal plant. Thus it is site specific.

- Due to mismatch of lunar driven period of 12 hours 25 min and human (solar) period of 24 hours, the optimum tidal power generation is not in phase with demand.

- Changing tidal range in two-week periods produces changing power.

- The turbines are required to operate at variable head.

- Requirement of large water volume How at low head necessitates parallel operation of many turbines.

- Tidal plant disrupts marine life at the location and can cause potential harm to ecology

**Advantages of Tidal Energy**

- The biggest advantage of the tidal power is besides being inexhaustible; it is completely independent of the precipitation (rain) and its uncertainty. Even a continuous dry spell of any number of years can have no effect whatsoever on the tidal power generation.

- Tidal power generation is free from pollution, as it does not use any fuel and also does not produce any unhealthy waste like gases, ash, and atomic refuse.

- These power plants do not demand large area of valuable land because they are on the bays (sea shore)

- Peak power demand can be effectively met when it works in combination with thermal or hydroelectric system.

**Tidal Energy Technology**

**The main components of a tidal plant, as shown in Fig. 7 are,**

- dam, barrage or dyke-a barrier constructed to hold water,
- sluice ways rapid controlled gates, used to fill a basin during high tides or emptying it during low tides, and
- a special, bulb-type power turbine-generator set steel shell containing an alternator and special Kaplan turbine with variable pitch blades. The tidal power associated with single filing or emptying or a basin may be estimated as follows.

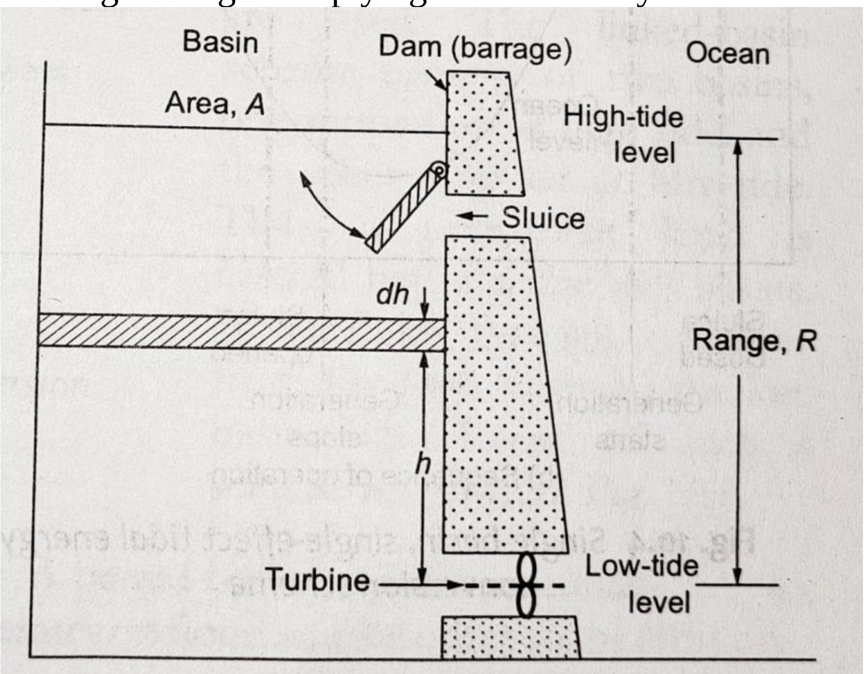


Fig. 7 Power generation from tides

**Tidal Range Power**

Consider water trapped at high tide in a basin of area A, and allowed to run out through a turbine at low tide as shown in Fig. 7. The potential energy in the mass of water stored in incremental head dh above the head h is:

$$dW = dm \,.\, g \,.\, h$$

but $dm = \rho \,.\, A \,.\, dh$

Thus $dW = \rho \,.\, A \,.\, g \,.\, h \,.\, dh$

Total potential energy of water stored in the basin is:

$$W = \int_0^R \rho \,.\, A \,.\, g \,.\, h \,.\, dh$$

$$W = \frac{1}{2} \rho \,.\, A \,.\, g \,.\, R^2 \text{ joules}$$

where $\rho$ = density of water

$g$ = gravitational constant

As the time between consecutive high and low tides is 6 hours 12.5 min (= 22,350 s), this power is to be utilised within this period.

Assuming an average sea-water density of 1025 kg/m³, the average theoretical power generated in one filling or emptying of the basin is:

$$P_{av} = \frac{1025 \times 9.80 \times A \times R^2}{2 \times 22{,}350}$$

$$P_{av} = 0.225 \times A \times R^2 \text{ watts}$$

Thus, the tidal power developed is directly proportional to (i) area of basin, and (ii) square of the range.

The actual power generation by a practical system would be less than the average theoretical power given in the above expression due to frictional losses of the fluid, conversion efficiency of the turbine and generator and due to the fact that the turbine cannot be operated down to zero head, and thus full power generation potential cannot be utilized. The turbine has to be stopped when the head reaches a minimum value $r$ below which the operation becomes uneconomical; the above expressions are modified as:

$$W = \int_r^R \rho \,.\, A \,.\, g \,.\, h \,.\, dh \text{ joules}$$

$$W = \frac{1}{2} \rho \,.\, A \,.\, g \,.\, (R^2 - r^2)$$

$$P_{av} = 0.225 \times A \times (R^2 - r^2) \text{ watts}$$

$$P_{av}/A = 0.225 \times (R^2 - r^2) \text{ MW/km}^2$$

**OCEAN TIDES ENERGY CONVERSION SCHEMES**

The main tidal energy conversion schemes are the following,

(i) Single basin: single effect
(ii) Single basin: double effect
(iii) Two basin: linked basin
(iv) Two basin: paired basin and
(v) Tidal flow (or tidal current) schemes.

**Single basin: single effect scheme -** The single-basin scheme has only one basin as shown in Fig. 8. In the single-effect scheme, power is generated either during filing or emptying the basin. Two types of operation cycles are possible.

In the ebb generation cycle operation, the sluice way is opened to fill the basin during high tide. Once filled, the impounded water is held till the receding cycle creates a suitable head. Water is now allowed to flow through the turbine coupled to the generator till the rising tide reduces the head to the minimum operating point. The flow is held till the next generating cycle. The sequence of events is illustrated in Fig 8. This cycle is repeated and power is generated intermittently. In the flood generation cycle operation, the sequences are altered to generate power during filling operation of the basin. However, the sloping nature of the basin shores usually makes ebb generation the more productive method.

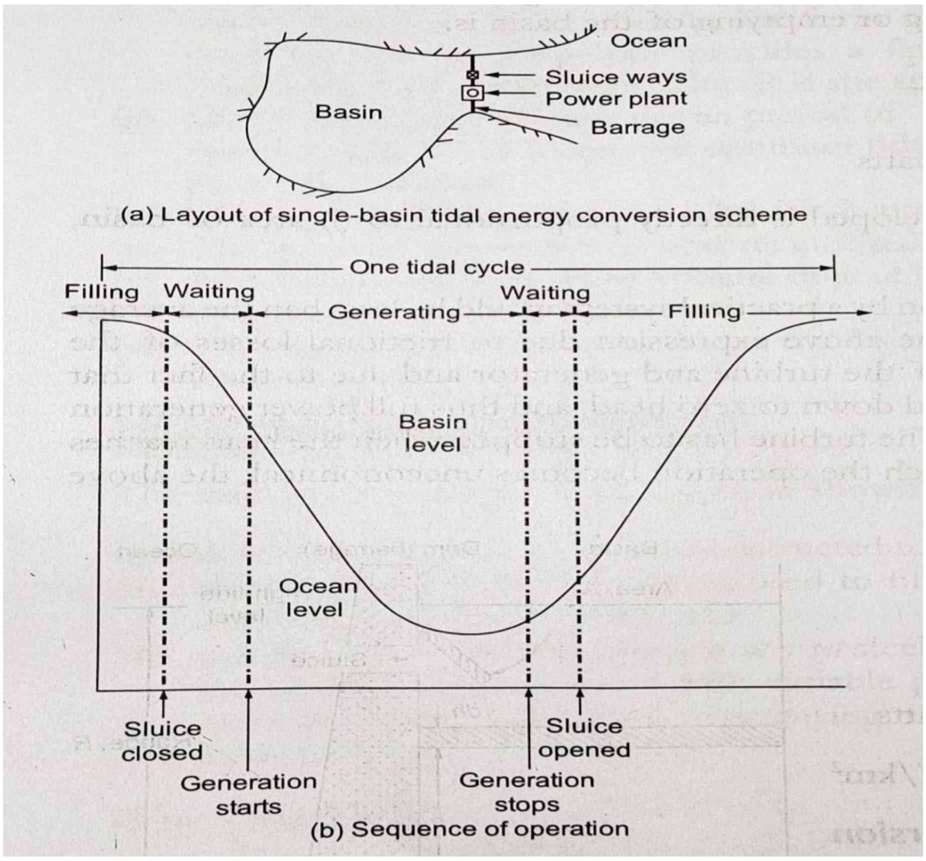


**Fig. 8 Single basin, single effect tidal energy conversion scheme**

Increased output can also be obtained by pumping during high tide to increase the basin level and therefore the generation head. The energy required for pumping must be borrowed and repaid. The pumping is done against a small head at high tide, whereas the same water is released through the turbine during low tide at a great head, producing a net energy gain.

**(ii) Single Basin: Double effect Scheme** – In single-basin, double-effect the scheme, power is generated on both flood and ebb. Two-way (reversible) hydraulic turbines are used. Pumping may also be used to increase the output. The routine is as follows:

1. Inward sluicing to fill the basin
2. Holding period
3. Ebb generation
4. Outward sluicing to empty the basin
5. Holding period
6. Flood generation

The routine is shown graphically in Fig. 9

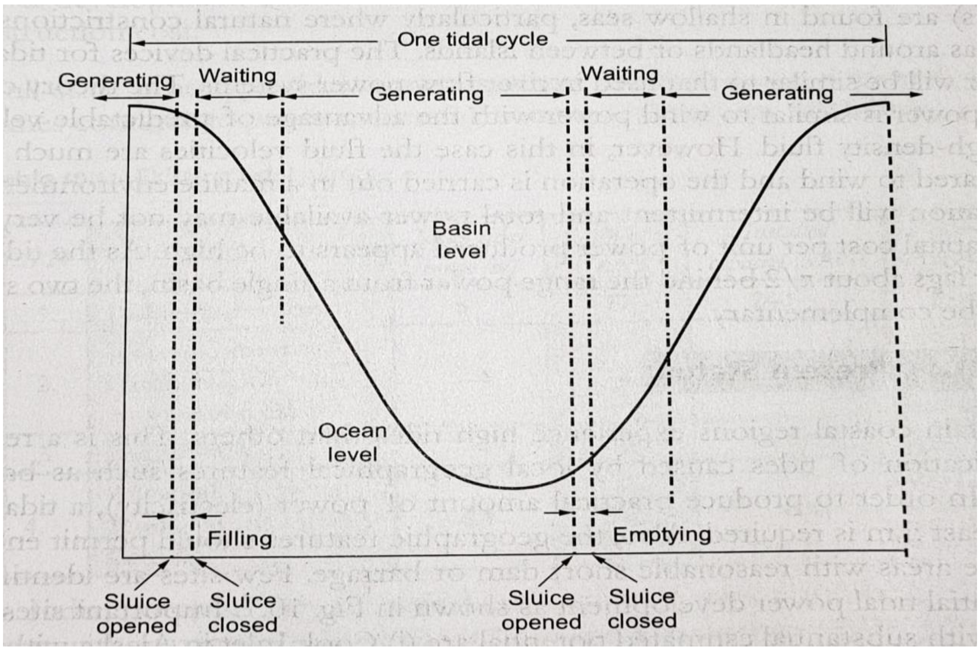


Fig. 9 Single-basin, double-effect tidal energy conversion scheme

**(iii)Two Basin:Linked-basin Scheme -** In order to maintain continuity of power supply, linked and paired basins schemes are used. The linked-basin scheme consists of two basins, one topped up at high tide, and the other emptied at low tide.

Thus, a permanent head is created between the two basins. Water flows through a turbine from the high basin to the low basin. The layout of such a scheme is shown in Fig. 10

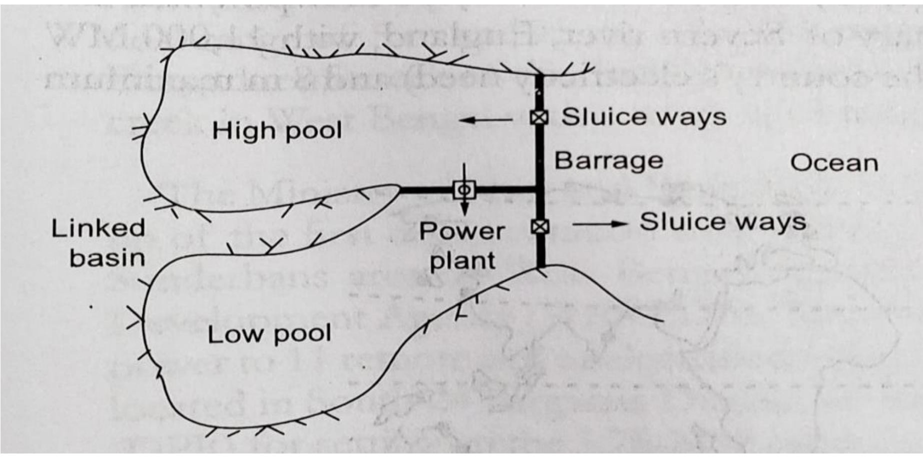


Fig. 10 Linked-basin tidal-energy conversion scheme

(iv)**Two basin: paired-basin scheme** A paired basin consists essentially of two single-basin schemes. One scheme generates on flood and the other on the ebb cycle. The output is almost, but not quite, continuous. Two basin schemes are generally found to be economically inferior to single-basin schemes.

**(v)Tidal Current Schemes** In order to explore the possibility of dispensing with the dam, its associated cost and environmental impacts, extraction of energy from tidal currents have been considered. Strong tidal currents (as high as about 5 m/s) are found in shallow seas, particularly where natural constrictions exist, such as around headlands or between islands. The practical devices for tidal flow power will be similar to that used in river flow power systems. The theory of tidal flow power is similar to wind power with the advantage of predictable velocities of high-density fluid. However, in this case the fluid velocities are much less as compared to wind and the operation is carried out in a marine environment. The generation will be intermittent and total power available may not be very large. The capital cost per unit of power produced appears to be high. As the tidal flow power lags about $\pi/2$ behind the range power from a single basin, the two systems could be complementary.

**Environmental Impacts**

Tidal energy is a renewable source of energy, which does not result in emission of gases responsible for global warming or acid rain associated with the use of fossil fuels. Changing tidal flows by damming a bay or estuary could, however, result in negative impacts on aquatic and shoreline ecosystems, as well as navigation and recreation. The barrage destroys the places that are home to many birds, fish and other animals.

Studies undertaken so far indicate that the impact at each site is different and depends greatly upon local geography. Very little is understood about how altering the tides can affect incredibly complex aquatic and shoreline ecosystems.