RAMAIAH
Institute of Technology

Department of Mechanical Engineering

UNIT 4

Ocean Energy

Programme	B.E (UG)
Semester	I/II
Course Name	Renewable Energy Sources
Course Code	ETC144
Course Credits	3-0-0
Unit 4	**Tidal Power:** Tides and waves as energy suppliers and their mechanics; fundamental characteristics of tidal power, harnessing tidal energy, advantages and limitations. **Ocean Thermal Energy Conversion**: Principle of working, OTEC power stations in the world, problems associated with OTEC. **Geothermal Energy Conversion**: Principle of working, Geothermal sources, problems associated with geothermal energy conversion, advantages and limitations.

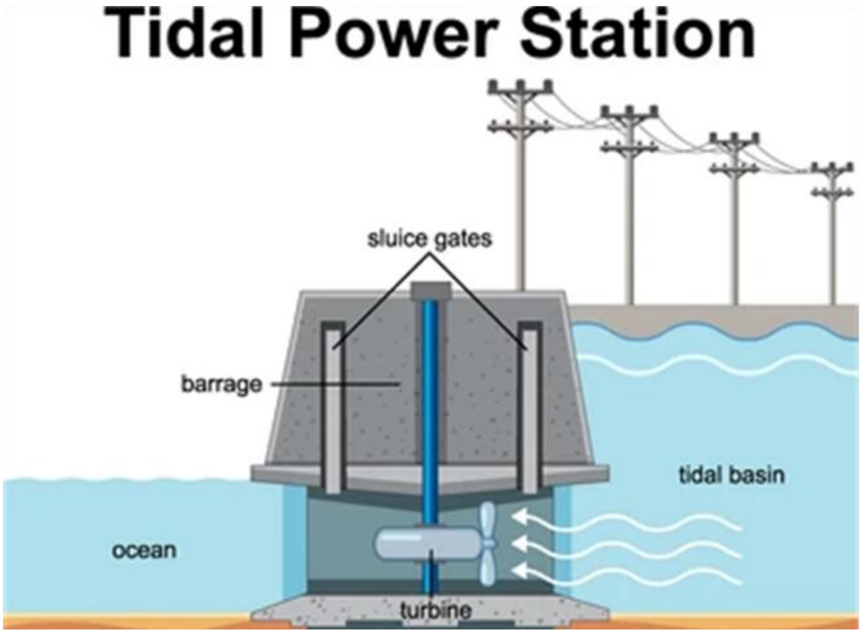
UNIT 4

Energy is required for the evolution of life forms on earth. However, a significant portion of the energy which we use today is obtained from non-renewable sources. This implies that once they are used up, they cannot be replenished. The most important source of non-renewable energy used extensively is fossil fuels which have taken millions of years to be formed. Thus, it is important to use them judiciously. This requires us to look for alternate sources. We know that energy exists in different forms in nature and that it cannot be created or destroyed. But it can be transferred from one form to another. The energy from nature- the sun, the wind, waves, tides, etc. can be converted into a usable form. One of these renewable sources of energy is tidal energy.

What Are Tides?

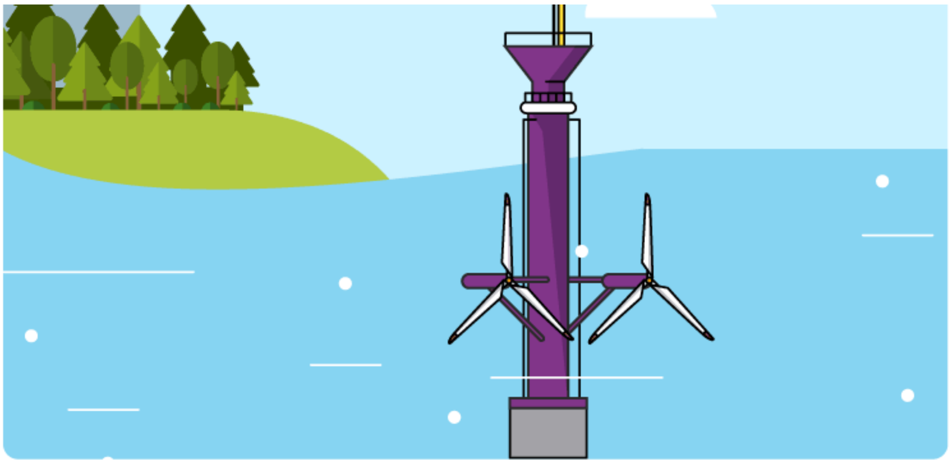
The gravitational forces of the sun and the moon combined with the rotation of the earth result in an alternate rise and fall of the sea levels. In one particular place, it usually occurs twice on a lunar day. The rise of the sea level is called the high tide, whereas the fall is called the low tide. When the earth and moon's gravitational field is in a straight line, the influences of these two fields become very strong and cause millions of gallons of water to flow towards the shore resulting in the high tide condition. Likewise, when the moon and earth's gravitational fields are perpendicular to each other, the influences of these fields become weak, causing the water to flow away from the shore resulting in a low tide condition.When the moon is perfectly aligned with the earth and the sun, the gravitational pull of the sun and the moon on the earth becomes much stronger and the high tides much higher and the low tides much lower during each tidal cycle. This condition occurs during the full or new moon phase. Such tides are known as spring tides. Similarly, another tidal situation emerges when the gravitational pull of the moon and sun are against each other cancelling their effects. This results in a smaller difference between the low and high tides due to the smaller pulling action on the seawater, thereby resulting in weak tides. These weak tides are known as neap tides. Neap tides occur during the quarter moon phase.

- The gravitational attraction of the moon and the sun upon the rotating earth produces tides in the sea. Rise and fall of tides occur twice a day.
- The highest level of tidal water is called high tide or flood tide,
- whereas the lowest level of tidal water is called low tide or ebb tide. The level difference between high and low tides is called the tidal range.
- The tidal range is time, season and location dependent. The maximum tidal range takes place at the time of new and full moon known as spring tides. If 5 m tidal range or above is available in a particular location, we can use it to operate a hydraulic turbine.



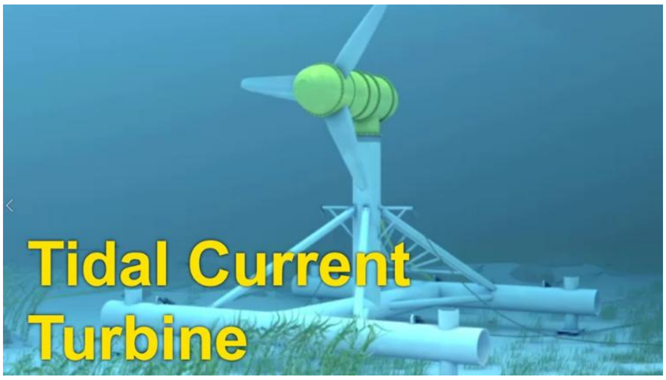
Tidal Energy

Tides are a regular phenomenon. They can be predicted over months and years in advance. This is why the energy from this massive movement of water can be harnessed and converted into a usable form of energy.



Tidal Energy Generator

Tidal Turbine and Wind Turbine



- Tidal turbines are similar to wind turbines in that they have blades that turn a rotor to power a generator.
- They can be placed on the sea floor where there is strong tidal flow. Because water is about 800 times denser than air, tidal turbines have to be much sturdier and heavier than wind turbines.
- Tidal turbines are more expensive to build than wind turbines but can capture more energy with the same size blades.

❖ **Several tidal power barrages operate around the world**.

➢ The Sihwa Lake Tidal Power Station in **South Korea** has the largest electricity generation capacity at **254 megawatts (MW).**

➢ The oldest and second-largest operating tidal power plant is in La Rance, **France**, with **240 MW** of electricity generation capacity.

➢ The next largest tidal power plant is in **Annapolis Royal in Nova Scotia**, Canada, with **20 MW of** electricity generation capacity.

China, Russia, and South Korea all have smaller tidal power plants

According to Indian government estimates, the country has a tidal energy potential of 8,000 MW.

➢ This includes about 7,000 MW in Gujarat's Gulf of Cambay,

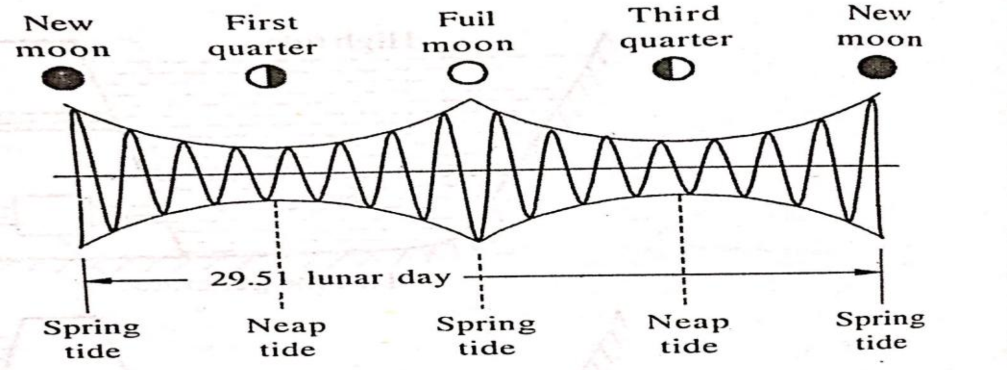
➢ 1,200 MW in Gujarat's Gulf of Kutch, and

➢ 100 MW in West Bengal's Sunderbans region's Gangetic delta.

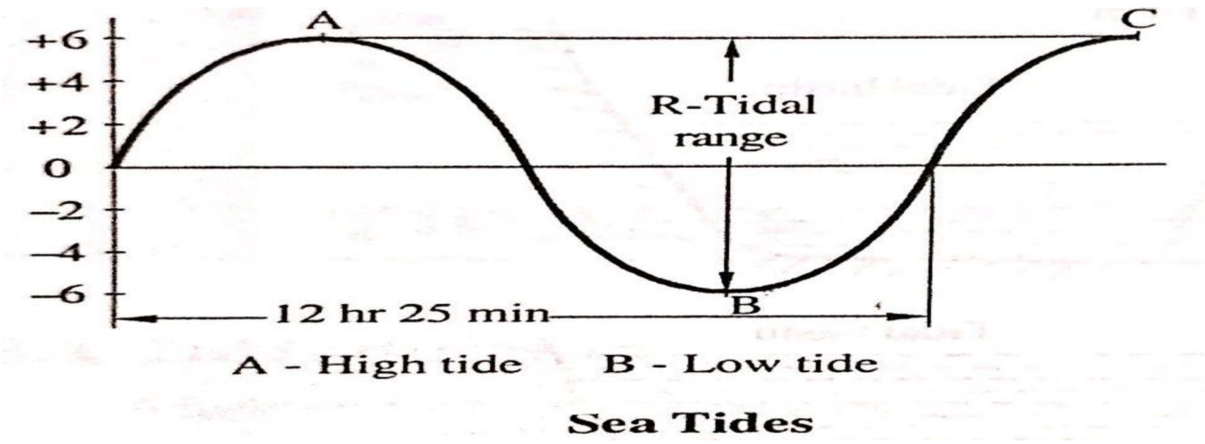
➢ **Vizhinjam wave energy plant**

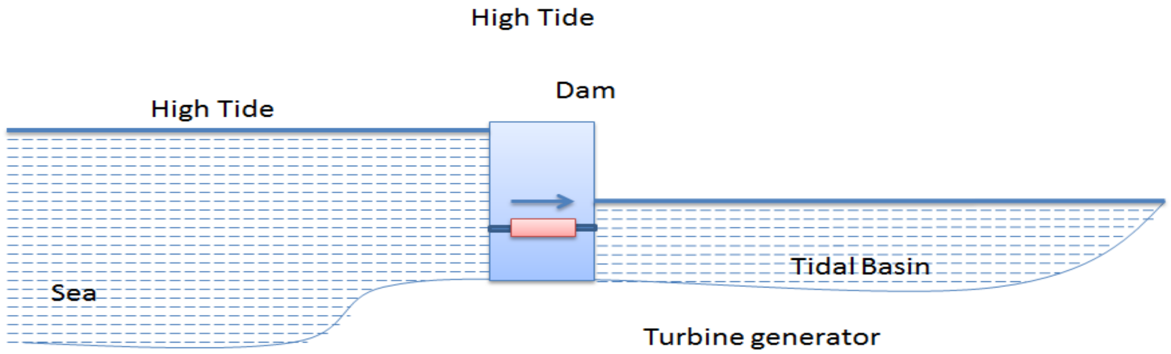
This led to the establishment of a 150 kW Pilot wave energy plant in 1991 at Vizhinjam in Thiruvananthapuram, Kerala.

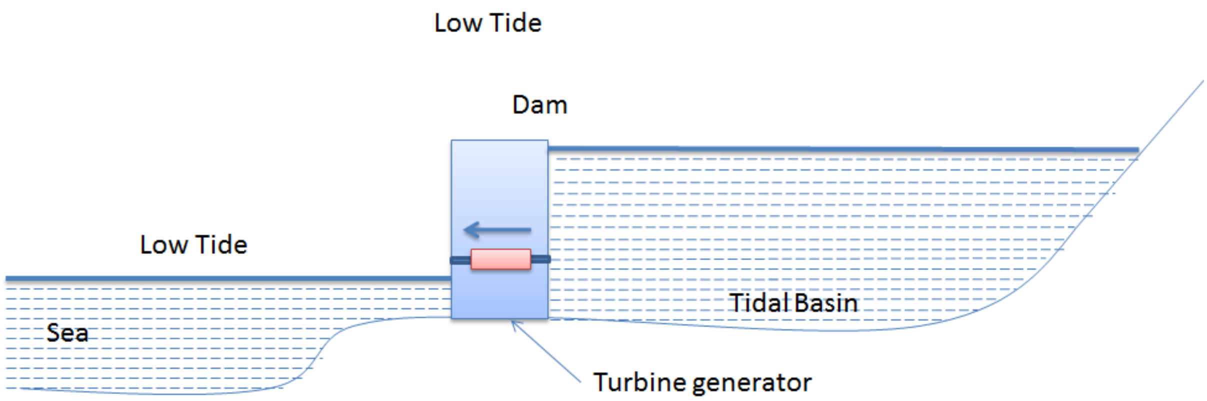
Working Principle of Tidal Power



Variation in tidal range in a lunar month







Tidal energy is generated from the Earth's oceanic tides. These tidal waves are the forces which form due to gravitational attraction exerted by celestial bodies. These forces create corresponding motions or currents within the world's oceans.

Due to the strong attraction to the oceans, a bulge within the water level is made, causing a short-lived increase in water level. Now due to Earth's rotation, this huge volume of ocean water meets the shallow water adjacent to the shoreline and creates a tide. This natural phenomenon is repetitive and takes place in an unfailing manner, due to the consistent rotation of the moon's orbit around the earth.

A tidal generator is required to convert the energy of tidal flows into electricity. The potential of a site for tidal electricity generation is directly proportional to greater tidal variation and better tidal flow velocities. These together can dramatically increase the tidal energy generation. As we know that Earth's tides take place due to the gravitational force of Earth with the Moon and Sun, so the tidal energy is practically inexhaustible and classified as a renewable energy resource. Movement of tides causes a loss of energy within the Earth-Moon system.

Characteristics of tides

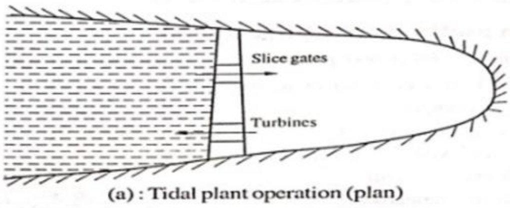
1. These are periodical phenomenon, but in any tidal cycle, no two tides are alike.
2. The tides are influenced by the relative positions of sun and moon and their distances from earth.
3. The tides at full moon and no moon are higher than the rest.
4. The tidal range R is not constant and varies continuously.
5. The mean tidal range varies from one place to another.
6. The tidal range is small at first quarter and third quarter moon.

Operation methods of utilization of tidal energy

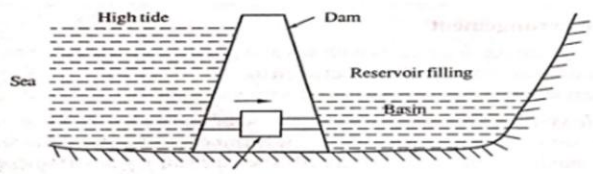
Classification of tidal power plants)

The Tidal Power Plants are broadly classified into

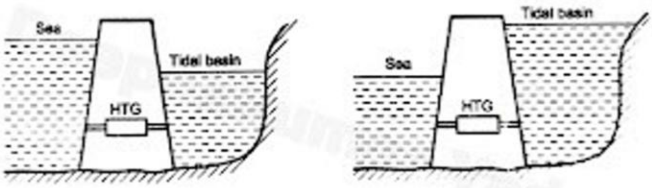
1. Single basin arrangement
    a. Single ebb-cycle system
    b. Single tide-cycle system
    c. Double cycle-system
2. Double basin arrangement



(a) : Tidal plant operation (plan)



(b): Sluice gates open, turbine shut off (sectional view)



HTG : Hydraulic turbine generator

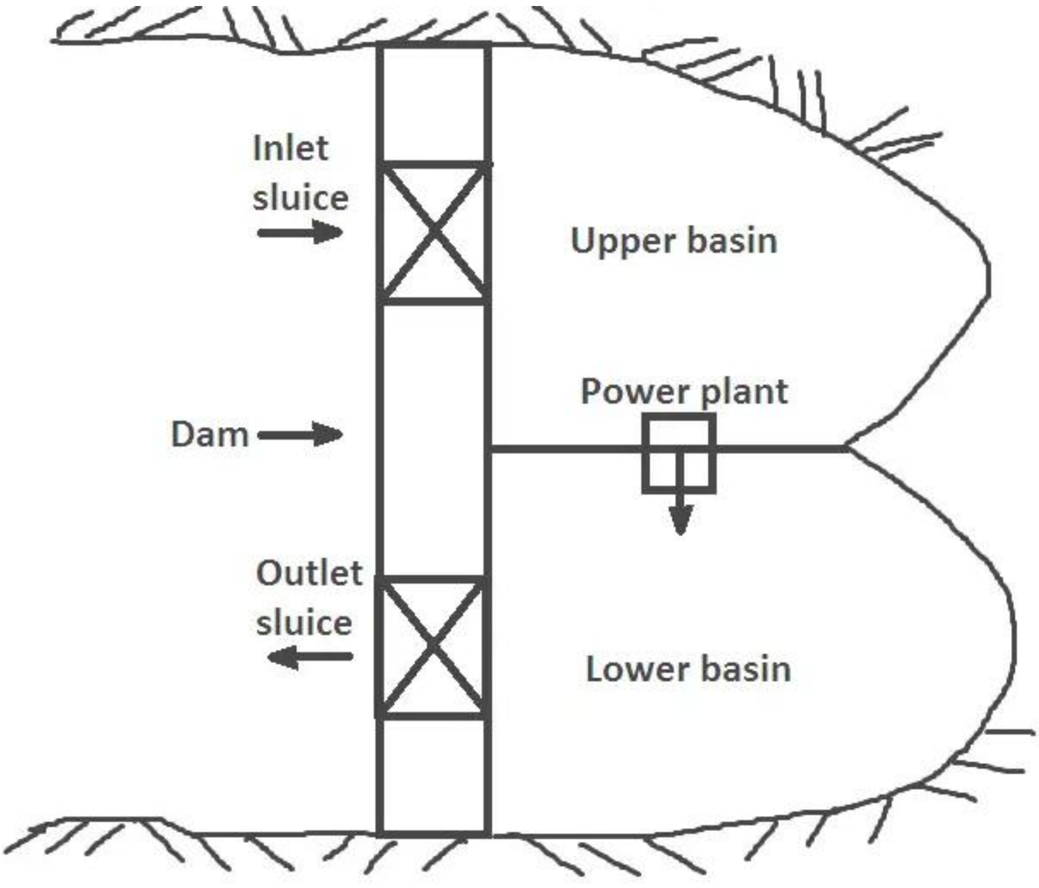
Double Cycle System

In a single basin tidal power plant, the powerhouse is located at the mouth of the basin. The hydraulic turbine in the powerhouse only operates during the discharge of water from the basin during low tide. The basin is filled again during the high tide. **Intermittent operation** is the main disadvantage of this system.

However, **in a double cycle system, power generation is possible during the low as well as high tide**. The direction of flow during the low and high tide alternates and production of power takes place during both the emptying and filling cycle of the basin.

Double Basin Tidal Power Plant Working

In a double basin tidal power plant, two basins at different levels are made, and a dam is provided in between them. Inlet and outlet sluice gates are made in the dam. The water level in the upper basin is maintained above the level of water in the lower basin.



Tidal power plant : Double basin system

The upper basin is filled with water during high tide, and the lower basin is evacuated during the low tide. Therefore, a permanent head is produced between the upper and lower basins.

When a sufficient head is created, the turbines of the power plant are started. The water flows from the upper basin to the turbine, which discharges into the lower basin, and electrical power is generated.

When the water level in the upper basin is maximum during high tide, the inlet sluice is closed, and the level of the water in lower basin keeps on rising due to the discharge of water by the turbine.

When the level of water in the lower basin equals during the low tide, the outlet sluice is opened, and it is closed when the water level reaches up to its minimum level. In this system, the power can be produced continuously during the emptying and filling of basins.

Challenges

- It has been nearly 40 years since India began efforts to assess and harness tidal power, but the country has yet to make any significant progress in this area, despite rapid progress in other renewable energy sources.
- A parliamentary panel has now requested that the Indian government reassess the potential of tidal power in India, investigate the practically exploitable potential, conduct additional research in the field, and develop a tidal power pilot project.
- In 2007 and 2011, India began construction on two tidal power projects in West Bengal and Gujarat, with installed capacities of 3.75 and 50 megawatts, respectively.
- However, both of these projects were suspended due to exorbitant costs.
- The project cost for the 3.75 MW Durgaduani tidal power project in West Bengal was Rs. 2.38 billion (Rs. 238 crore).
- The estimated cost of the 50 MW tidal power project in Gujarat's Gulf of Kutch was Rs. 7.5 billion (Rs. 750 crore) per megawatt of power.
- Exorbitant costs and environmental risks are two major reasons why tidal power projects have yet to be developed in India.

- Because of various obstacles, tidal power is not actively pursued on a global scale as well

Tidal Energy Advantages and Disadvantages

Advantages of Tidal Energy

- Renewable: Tidal energy is a renewable source of energy. It is generated by the combined effects of the gravitational force of the moon and the sun and the rotation of the earth. The power generation in tidal energy is possible due to the difference in the potential energies of the tides. Different kinds of power generators like stream generators, tidal barrages, and dynamic tidal power (DTP) use this.
- Green: Tidal power is an environmentally friendly source of energy. It does not produce any harmful gas. One of the major benefits of tidal energy is that it utilizes a very small space for energy production.
- Predictable: Tidal currents or waves are highly predictable. High and low tide develops with the ocean as per some renowned cycles. This makes it easier to develop a system with exact dimensions to produce energy, as we already have knowledge of what kind of waves the equipment will be exposed to. This is the reason that the tidal stream generators are similar to that of wind turbines.
- Effective at Low Speeds: It is possible to generate electric power at very low speeds because the density of water is much more than that of air. Power can also be generated at a water speed of about 1 m/s.
- Tides are fluently predictable
- Affordable to maintain
- Reliable and renewable source of energy
- High energy viscosity than other renewable energy forms
- It produces no hothouse feasts or other waste
- Vertical-axis turbines and coastal turbines are affordable to make and have a lower environmental impact
- Tidal turbines are 80% effective, which is more advanced than solar or wind energy creators.
- Drumfires reduce the damage of high tidal surges on the land.

Disadvantages of Tidal Energy

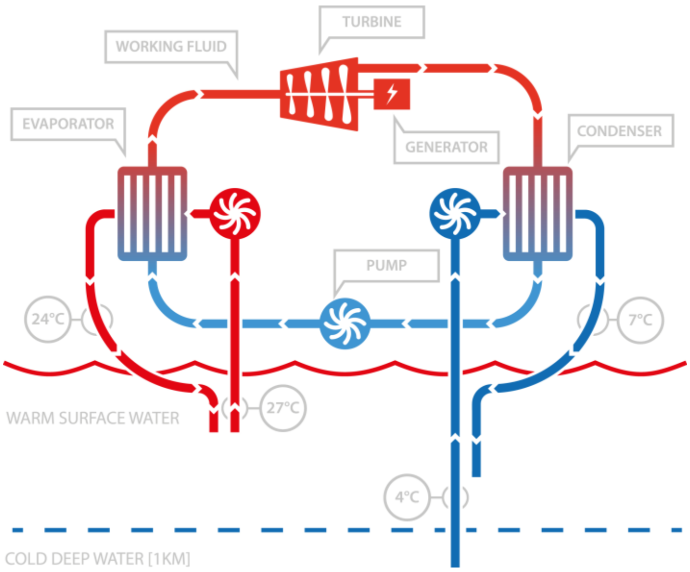
1) Cost of construction of tidal power plant is high.
2) There are very few ideal locations for construction of plant and they too are localized to coastal regions only.
3) Intensity of sea waves is unpredictable and there can be damage to power generation units.
4) Influences aquatic life adversely and can disrupt migration of fish.
5) The actual generation is for a short period of time. The tides only happen twice a day so electricity can be produced only for that time.
6) Frozen sea, low or weak tides, straight shorelines, low tidal rise or fall are some of the obstructions.
7) Usually the places where tidal energy is produced are far away from the places where it is consumed. This transmission is expensive and difficult.

Ocean Thermal Energy Conversion (OTEC)

Ocean Thermal Energy Conversion (OTEC) is a renewable energy technology that uses the natural temperature difference in oceans to produce clean, reliable electricity, day and night, year-round.

OTEC:

- OTEC or ocean thermal energy conversion is a technology which converts solar radiation absorbed by the oceans to electric energy. The ocean's can be considered as the world's largest solar energy collector as it covers two third of the earth surface.
- The heat from the warm ocean surface and cold from the deep ocean drives a Rankine Cycle, which produces electricity.
- The technology is viable primarily in equatorial areas where the year-round temperature differential is at least 20 degrees Celsius



The surface water temperature is about 27°C and at 1 km directly below, the temperature is about 4°C. The reservoir of surface water may be considered a heat source and the reservoir of cold water (1 km below) is considered a heat sink. The concept of ocean thermal energy conversion is based on the utilization of temperature difference between the heat source and the sink in a heat engine to generate power.

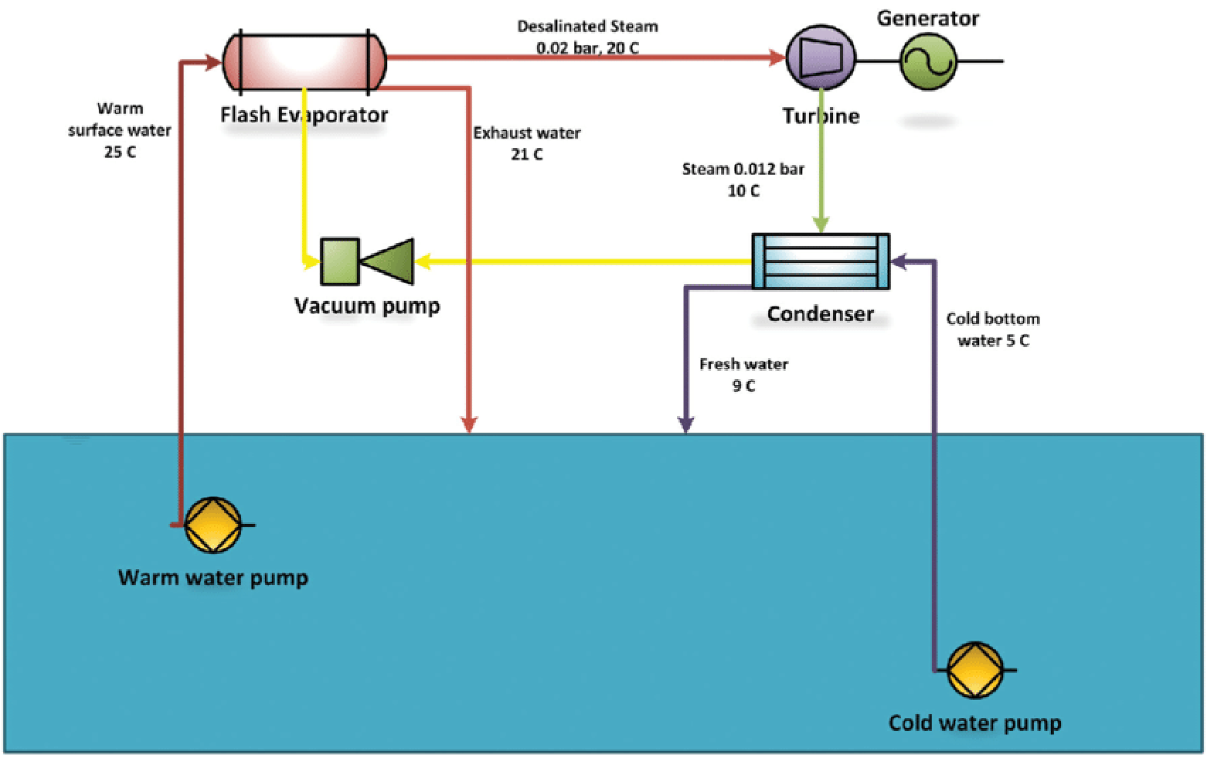
There are basically three types of OTEC power plant:

1. Open cycle or Claude cycle.

2. Closed cycle or Anderson cycle.

3. Hybrid cycle

1. Open cycle or Claude cycle.



In this cycle, the seawater plays a multiple role of a heat source, working fluid, coolant and heat sink. Warm surface water enters an evaporator where the water is flash evaporated to steam under particle vacuum. Low pressure is maintained in the evaporator by a vacuum pump. The low pressure so maintained removes the non-condensable gases from the evaporator. The steam and water mixture from evaporator then enters a turbine, driving it thus generating electricity. The exhaust from the turbine is mixed with cold water from deep ocean in a direct contact condenser and is discharged to the ocean. The cycle is then repeated. Since the condensate is discharged to the ocean, the cycle is called open.

Flash evaporation

In the evaporator the pressure is maintained at a value (0.0317 bar) slightly lower than the saturation pressure of warm surface water at 27°C (0.0356 bar). Hence, when the surface water enters the evaporator, it gets ‘superheated’This.

super heated water undergoes ‚volume boiling‛ causing the water to partially flash to steam.

2. **Closed cycle or Anderson cycle.**

Here, a separate working fluid such as ammonia, propane or Freon is used in addition to water. The warm surface water is pumped to a boiler by a pump. This warm water gives up its heat to the secondary working fluid thereby losing its energy and is discharged back to the surface of the ocean. The vapours of the secondary working fluid generated in the boiler, drive a turbine generating power. The exhaust from the turbine is cooled in a surface condenser by using cold deep seawater, and is then circulated back to the boiler by a pump.

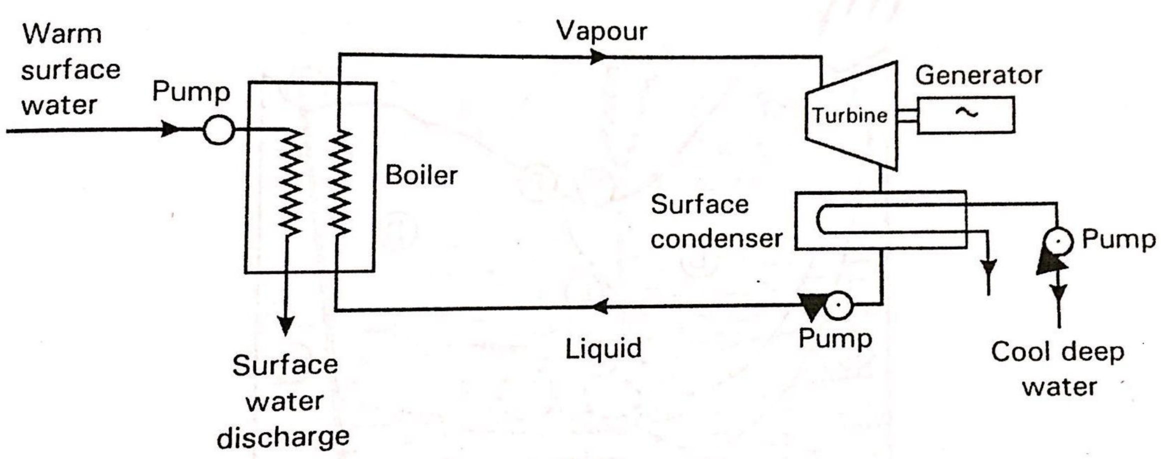
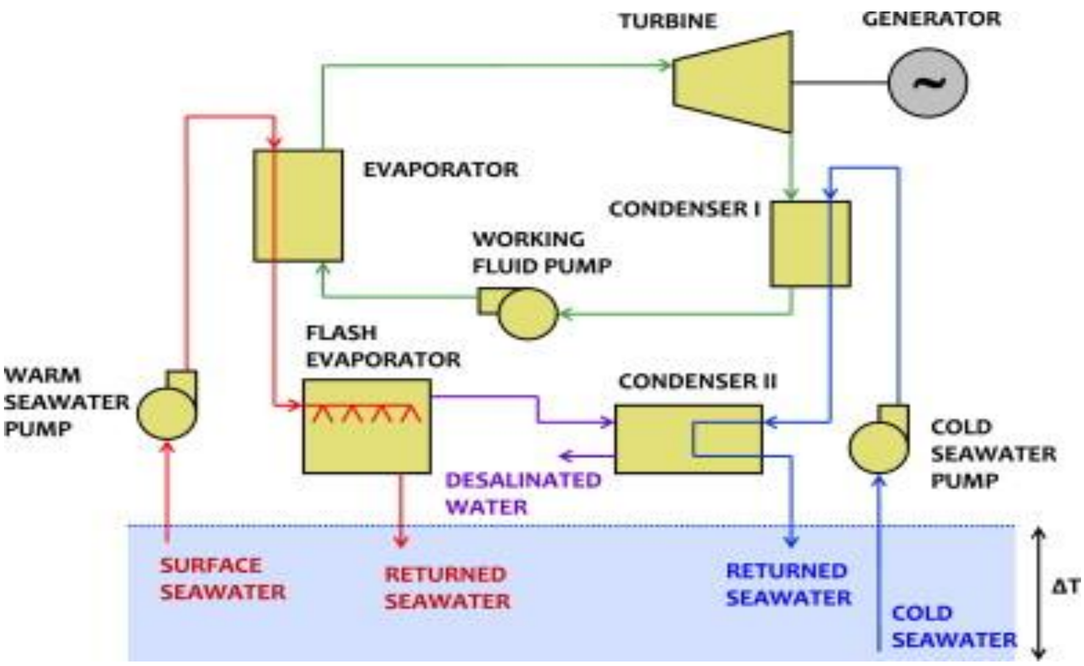


Fig. 7.14 Schematic of a closed cycle OTEC plant

3. Hybrid cycle



The Hybrid OTEC cycle combines aspects of closed and open cycle OTEC systems. In closed OTEC cycles, a working fluid such as ammonia or other refrigerant are utilized with heat exchangers. The heat exchangers are often titanium to handle seawater conditions. Open OTEC produces fresh water with no working fluid through the use of a vacuum chamber to lower the boiling point of water, but requires very large turbines to take advantage of low-pressure steam. The Hybrid Cycle hopes to take advantage of the benefits of both systems. Surface seawater is vaporized in flash (vacuum) chamber. As salt and other components of seawater are left behind, lower-cost materials can be utilized in a heat exchanger to cool the vapor into desalinated water. To cool the vapor, a working fluid is used on the other side, and as it warms, the working fluid vaporizes, such as in a closed OTEC system. The vapor expands through a turbine, which drives a generator creating electricity. A final heat exchanger returns the vapor back into a liquid for reuse in the cycle though the cold-energy of deep ocean water. We look forward to the results of this research and demonstration project.

Ocean Thermal Energy Conversion Advantages and Disadvantages

Advantages:

- It is a clean and pollution free renewable source of energy.
- Power generated by this system is continuous. Only a small variation in output takes place from season to season. In simple words we can say, the system is independent of weather.
- By making only small changes in design, conventional power plants can be used in this system.
- It can produce the desalinated water and nutrients for mariculture at the same time.

Disadvantages:

- The capital cost is very high.
- The overall efficiency of the system is very low.
- The open cycle system needs very large sized turbine due to the low pressure of steam.
- In the closed cycle system, the working fluid is very expensive.
- The cost of power generation per kWH is very high.

OTEC power stations in the world

- OTEC Plant in Lakshadweep in india-65 kW
- Okinawa Prefecture, Japan- 1 MW

- Makai Ocean Engineering went operational in Hawaii in August 2015
- Bahamas, USA-10 MW
- Hainan, China -10 MW
- United States Virgin Islands
- Kiribati-1 MW
- Martinique-10.7 MW
- Maldives-150 kW

Problem Associated with the OTEC

- The sea water more corrosive, thus the life of the plant is less
- The water can be evaporated at low temperature only thus corresponding pressure is low thus only smaller output are possible
- Much pumping work is required to remove the non-condensable gases
- The specific volume is more due to low pressure and temperature. This necessities a large turbine
- The plant have to be based at lands some distance away from the OTE source this requires long pipe lines to convey cold sea water to the power plant
- Due to low out[put, large componets etc cost of the OTE power plant is very high
- The plant requires expensive and large size structures for installation and operation.

Geothermal Energy

Heat has been radiating from the Earth's core for billions of years. This heat is originated since the formation of the Earth and it is continuously regenerated by the decay of radioactive elements. The rate of this regeneration of geothermal heat is so high that it makes the geothermal energy a renewable resource. Near the Earth's core, the temperature ranges about 5500 degree Celsius. This heat is basically the thermal energy stored inside the Earth's core and the Earth's crust acts like an insulator and keeps the heat trapped inside. This thermal energy is known as geothermal energy. (geo=earth and thermal=heat). This energy is estimated to be one or two orders larger than all the energy recoverable from nuclear sources.

The heat trapped inside the core (by the Earth's crust) is transferred to the surface by the following ways:

Direct heat conduction

Bubble like magma that buoys up to the surface

Rapid injection of magma into deep, natural rifts

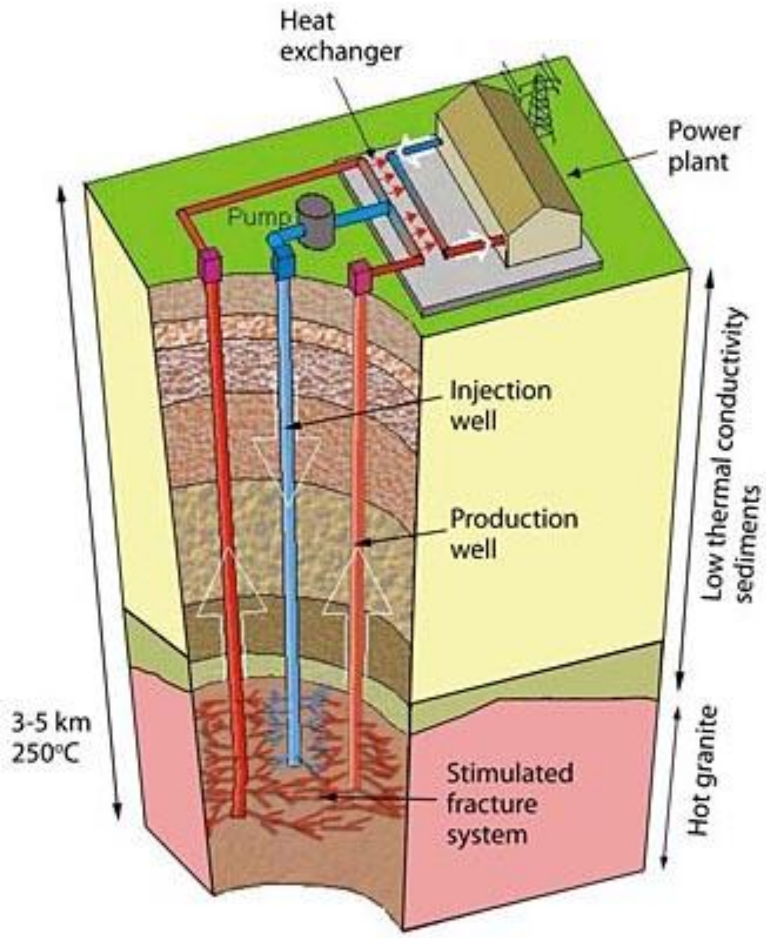
Direct heat conduction does not produce much heat on the surface. Also, magma buoys up to the surface only at selected locations like active volcanoes. Whereas magma is injected into deep rifts and causes heating of the underground water.

This geothermal energy rises upwards due to one of the above reasons and causes large amounts of underground water to be heated on or below the surface of the Earth. Such locations are called Geothermal reservoirs. Such reservoirs are either on the surface in the form of hot springs or underground reservoirs which are reached by drilling wells.

The heat energy in geothermal reservoirs can be carried up to the surface and

utilized to produce electricity by geothermal power plants.

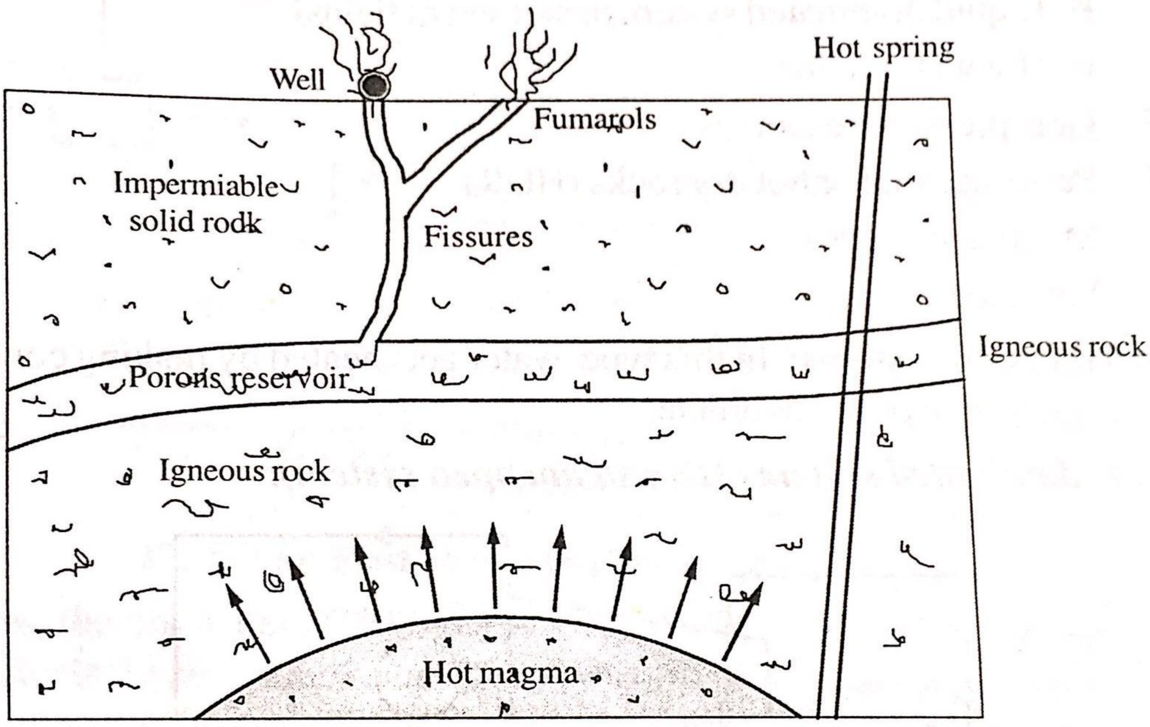
Geothermal heating using has been used for bathing since Paleolithic times and for space heating since ancient Roman times. More recently geothermal power, the term used for generation of electricity from geothermal energy, has gained in importance of wetlands. It is estimated that the earth's geothermal resources are theoretically more than adequate to supply humanity's energy needs, although only a very small fraction is currently being profitably exploited, often in areas near.



Geothermal sources

There are five kinds of Geothermal sources

1. Hydro thermal convective systems
   a. Vapour dominated or dry steam fields
   b. Liquid dominated system or wet steam fields
   c. Hot water fields
2. Geo-pressure resources
3. Petro-thermal or hot dry rocks (HDR)
4. Magma resources
5. Volcanoes



Types of Geothermal Plant

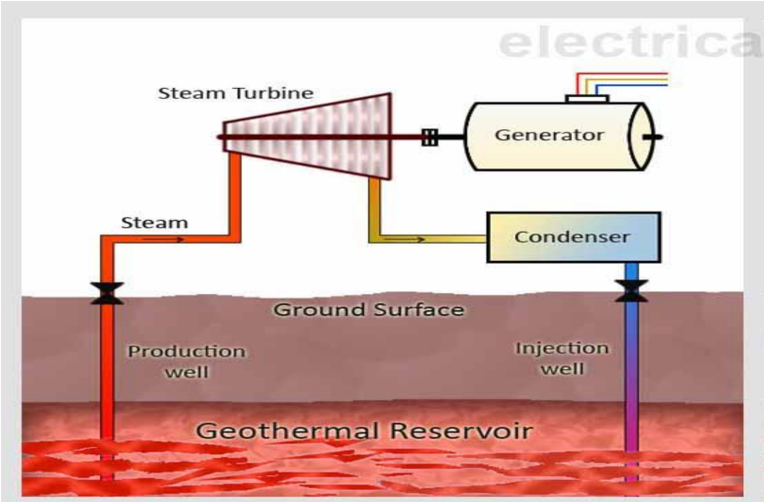
Geothermal Power Plants

A geothermal power plant uses steam obtained from these geothermal reservoirs to generate electricity. Wells are drilled at the appropriate locations to bring this geothermal energy up to the surface. A mixture of steam and water is collected from the production well. Steam separators are employed to separate the steam and use it to operate turbines. The further process is quite similar to a thermal power plant - steam turbines run the generators and, hence, electricity is generated. The condensed steam and the water collected from the production well are injected back into the reservoir through the injection well.

This is, however, a **general working principle of a geothermal power plant**. The particular working of the plant depends upon the type of the plant.

1. **Dry Steam Plant**

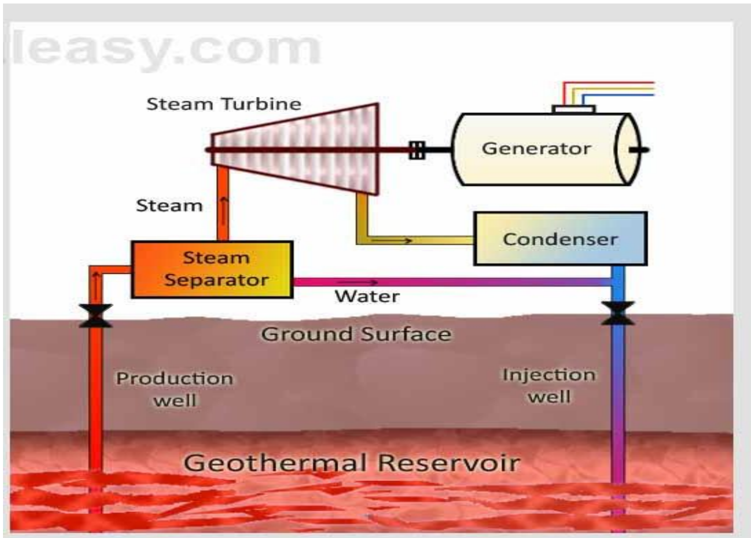
This is the simplest and oldest type of geothermal plant. It directly uses steam from the reservoir to operate the turbine. The steam is collected from the production well and used to operate low-pressure turbines. Hence, the working fluid is steam. The used steam is then condensed and injected back through the injection well.



Dry Steam Plant

2. Flash Steam Plant

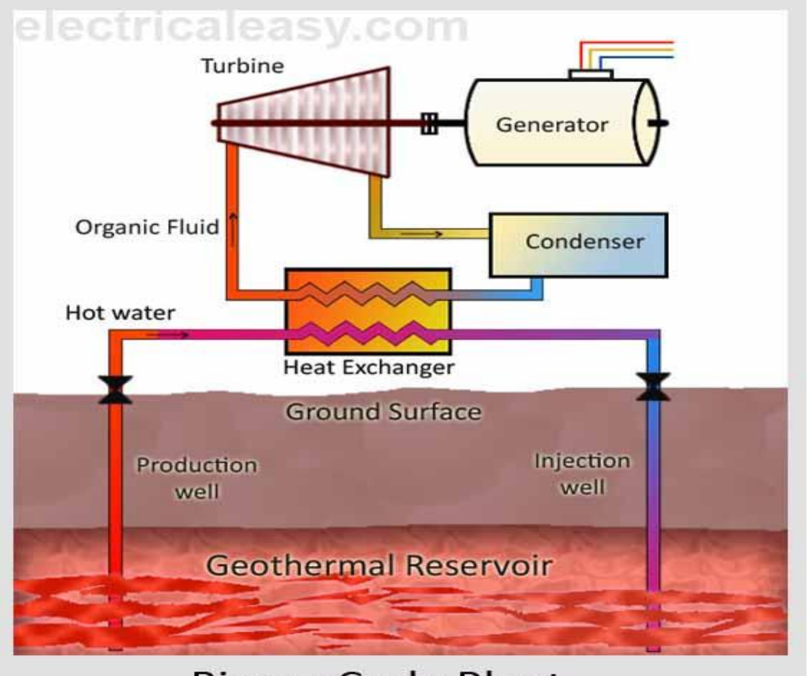
Flash steam power plants are the most commonly employed geothermal plants today. They operate on the geothermal reservoires having water temperature greater than 180 degree celcius. The high pressure hot water from the reservoir flows up through the production well due to its own pressure. The pressure decreases as the water flows upwards and, hence, some of it gets converted into steam. The steam is seperated from the water by steam seperator and sent to drive the steam turbine. The unused water as well as the condensed steam are injected back through the injection well.



Flash Steam Plant

3. **Binary-cycle power plants**

Binary power plants are the recent development. They have made it possible to produce electricity from geothermal reservoirs with temperatures lower than 150 degree celcius. In these plants, hot water from geothermal reservoir is used to heat up an another organic fluid having a lower boiling point. Thus, here, the working fluid is the secondary organic fluid and not the water from reservoir. The heat energy from the water is transferred to the working fluid in the heat exchanger. As a result, the working fluid vaporizes, and then drives the turbines. The spent fluid passes through the condenser and the cycle repeats. The water is injected back into the reservoir through the injection well.



Binary Cycle Plant

- **Geo Pressure Resource :** In this resources, high temperature & high pressure water (brine) is present in reservoir. A substantial amount of methane is dissolved in pressurised water at 160°C when pressure released methane will be released . Depth 2400 to 9000m
- **Hot dry rock (Petro thermal System)**: For the hot rock artificially injected water through specially formed paths. The temperature range from 150 to 300°C.
- **Magma resources**: Molten rock at temperature greater than 650°C.

Advantages And Disadvantages Of Geothermal Power Plants

Advantages

- Renewable energy source
- No harmful gases emitted
- No green house effect
- Cost of Fuel is negligible
- Capital cost is 40-60% less than thermal and Nuclear plants
- Short construction period
- Corrosive effects of steam tackled by advanced metallurgy

Disadvantage

- Availability at certain regions only (Where magma is nearer to the surface)
- Low efficiency (10-12%)

Problem associated with Geothermal Conversion.

1. Solid particles and non-condensable gases (H_2, CO_2, N_2 , NH_3)
2. Discharge of used water
3. Noise Pollution
4. Subsidence
5. Seismic activity
6. Fog due to escaping of steam
7. Sand and other solid particles

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