# MET445- RENEWABLE ENERGY ENGINEERING



**Department of Mechanical Engineering**

**MEAEC**

# Module 4

Ocean Energy – Devices for Wave Energy conversion, Ocean Thermal Energy Conversion (OTEC): Principle of OTEC system, Methods of OTEC power generation – Open Cycle (Claude cycle), Closed Cycle (Anderson cycle) and Hybrid cycle (block diagram description of OTEC); Geothermal energy: Introduction, hot dry rock resources, magma resources, vapor and liquid dominated systems, binary cycle, advantages and disadvantages

# Ocean energy

- Tremendous amount of energy is available in oceans and seas due to waves and tides, which are mechanical forms of energy related to kinetic and potential energy of the ocean water.
- Oceans also have thermal energy due to solar heating of ocean water.

# Wave energy

- Like most other renewable energy sources, wave energy is ultimately caused by solar energy.
- Ocean and sea waves are caused by wind, and wind is caused by uneven solar heating of earth and water bodies and thus resulting temperature fluctuations.

# Wave energy conversion

- Waves with an amplitude of 2 m and period of 10 s are of considerable interest for power generation with wave energy fluxes averaging between 50 kW and 70 kW per metre width of oncoming wave.
- Wave energy can be better concentrated than the solar energy.
- Ocean wave energy is the primary energy.

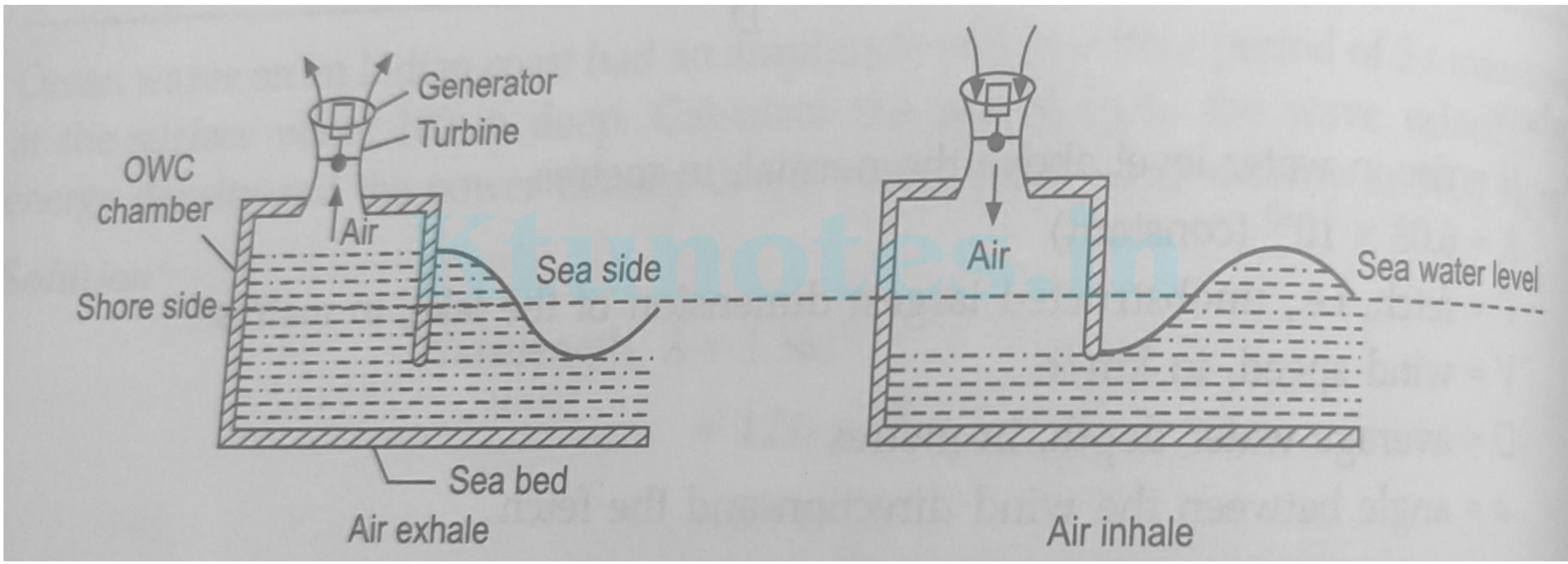
# Wave energy conversion

- A demonstration plant of 150 kW capacity for conversion of wave energy into electrical energy has been built at Vizhinjam near Trivandrum.
- This site was selected considering its good wave power potential, easy access to deep water, away from cyclonic zone and nearness to the available infrastructural facilities.
- This plant was commissioned in October 1991.

# Principle of Wave energy Plant

- The wave energy plant utilizes an “oscillating water column” chamber and a self rectifying air turbine to produce power.
- The device works similar to  the operation of a bellow.
- Ocean wave enters the chamber inside the caisson and cause the water mass to move up and down producing a bidirectional air flow through an opening at the top of the caisson.

# Principle of oscillating water column device giving bidirectional air flow to unidirectional rotating turbine



- The special design of turbine makes it rotate unidirectionally even though actuating air flow is bidirectional.
- The turbine devices an induction generator connected to the grid.

# Wave energy conversion Devices

- Wave energy is a combination of kinetic and potential energies available in sea waves.
- The forward motion of sea water can easily be seen on sea beaches, lashing up to 100 meters.
- In deep sea this forward motion of the wave strikes the ships, depicting the presence of kinetic energy.

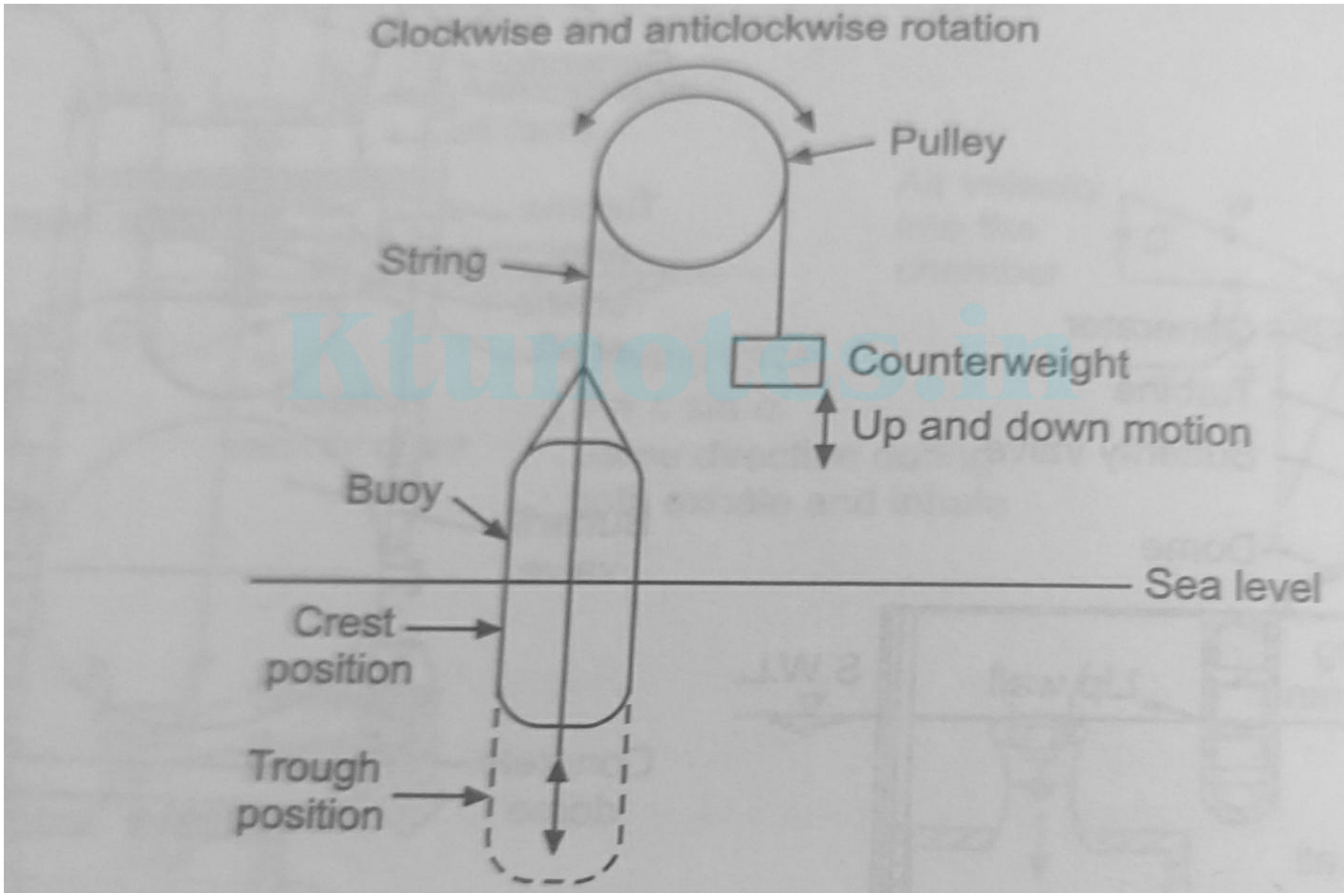
- The potential energy is due to rise of sea water at the wave crest.
- The difference of head between the crest and the through of sea wave is the potential energy.

# Wave energy conversion Devices

## 1. Buoy type machine

- The buoy is a floating part of a system which rises and falls with rise and fall of sea waves.
- The buoy oscillates up and down with the wave, the energy can be exhibited on a pulley with a string and counterweight arrangement.
- The up and down motion of the counterweight can be converted into to and fro motion of a piston which can operate a machine or a generator.

# Oscillating buoy with a string, pulley and counterweight

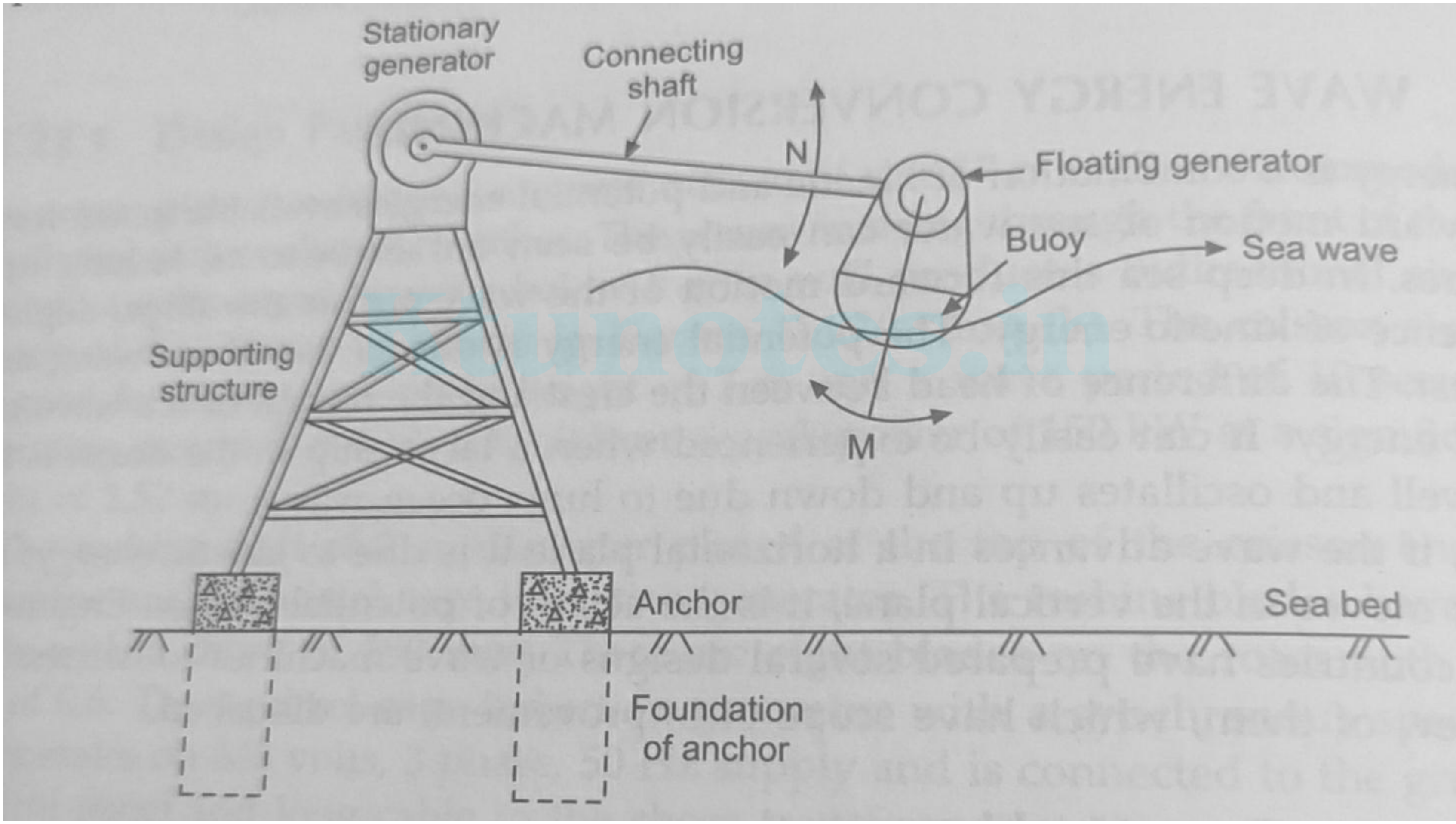


# Wave energy conversion Devices

2. **Dolphin type wave energy generator**

- Designed in Japan.
- A supporting structure is built in the sea bed to provide a firm position for the equipment.
- The structure is erected on pile foundations.
- One generator is installed on rolling motion.
- The gear arrangement with stationary generator rotates the rotor to generate electric power.

# Dolphin type wave energy generator



# Wave energy conversion Devices

## 2. Dolphin type wave energy generator

- The buoy is at the other end of the connecting rod floats and has two motions, namely rolling motion and oscillatory motions represented by N and M respectively.
- The floating generator collects wave energy from the buoy through a gear arrangement and continuously generates power.

$$\text{Power density, } \frac{P}{B} = 1740a^2T, \text{ in W/m}$$

where

$B$ = width of the wave, in metres

$a$ = amplitude of the wave, in metres

$T$ = wave period, in seconds



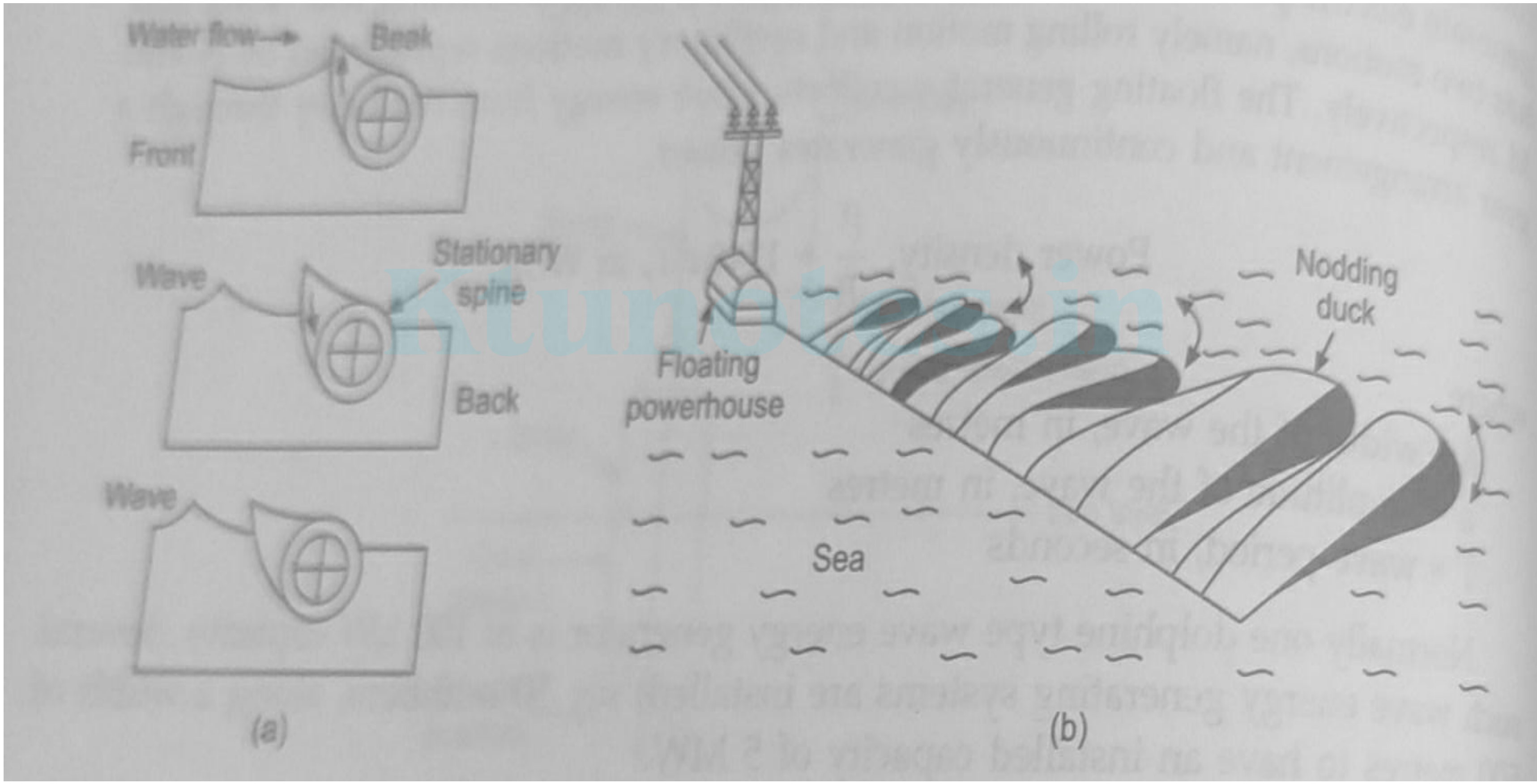
Normally one Dolphine type wave energy generator is of 100 kW capacity.

# Wave energy conversion Devices

## 3. Oscillating Ducks

- Designed in Scotland.
- It is a float type wave energy conversion plant in which several duck shaped devices (each 25 m long) are installed in a linear width-wise array along a line which is perpendicular to the direction of the wave.
- The system consists of a long cylindrical spine of 15 m diameter on which cam shaped ducks are installed in an array to form an assembly.

# (a) Phases of duck motion, (b) oscillating ducks with a floating powerhouse



# Wave energy conversion Devices

**3. Oscillating Ducks**

- It responds to the incoming wave with a nodding action.
- When the forward moving wavefront strikes the head on the face of the ducks, wave energy is passed on and the ducks starts to oscillate.
- The face of the duck is designed for maximum wave energy absorption.

# Wave energy conversion Devices

## 3. Oscillating Ducks

- Power is generated by the relative motion of the ducks where the wave energy is converted into mechanical energy.
- The cylindrical spine transfers motion through linkages and gears to the generator rotor.
- The overall length of the cylindrical spine varies between 100 m and 500 m.

# Wave energy conversion Devices

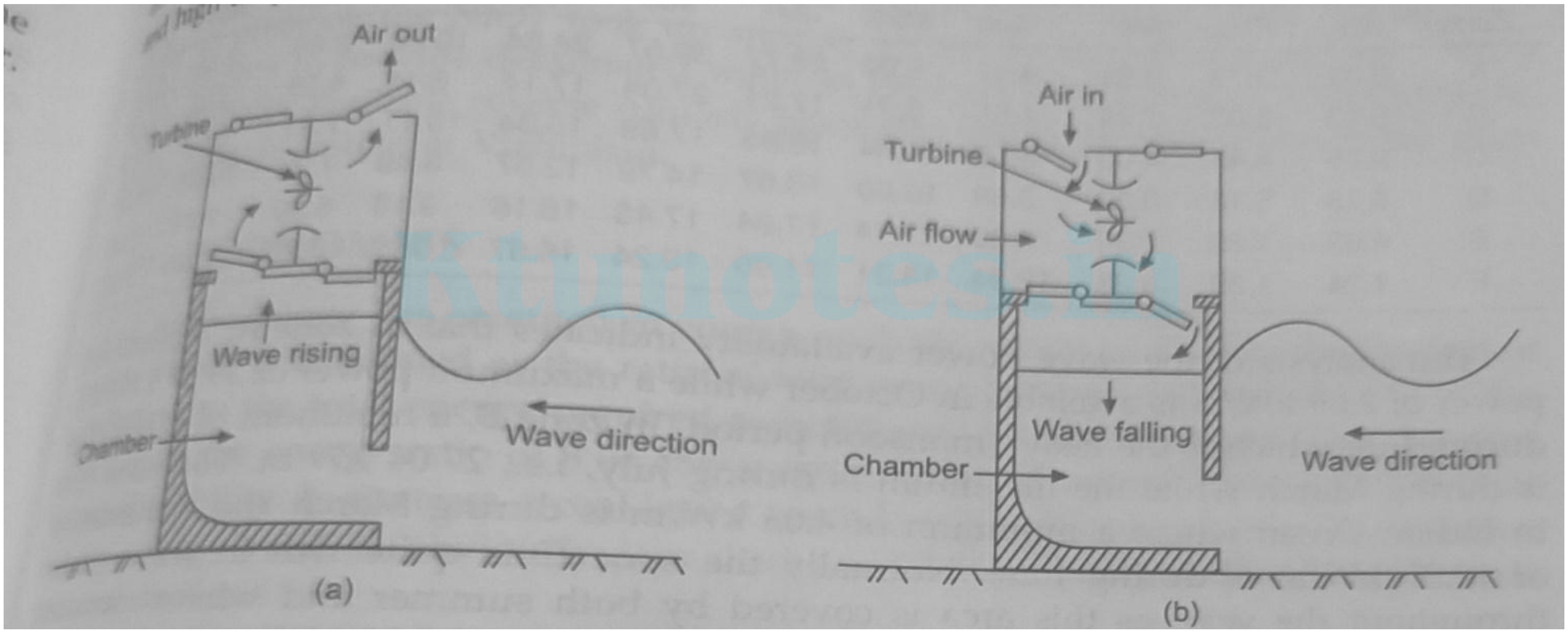
## 3. Oscillating Ducks

- To achieve a highly efficient absorption it is necessary to mount a series of ducks on a non-movable spine.
- If the spine is sufficiently long (more than wavelength), the angular distribution of the waves incident on this structure will produce phase cancellations of translation force components along the spine and the spine will remain stationary.

# 150 kW conversion system in Vizhinjan, TVM

- The wave power available at the site is nearly 13 kW/m.
- The wave energy conversion system consists of an oscillating water column, a chamber floating in the sea experiencing wave action through a side opening.
- The chamber size is 10 x 10 m with  a height of 15 m.
- The turbine is 2 m diameter and coupled to an induction generator.

# (a) OWC wave energy conversion system (wave rising) (b) OWC wave energy conversion system (wave falling)



- The wave patterns are irregular in amplitude, phase and direction, so the wave energy devices parameters match the irregular slow medium and high amplitude wave motion.

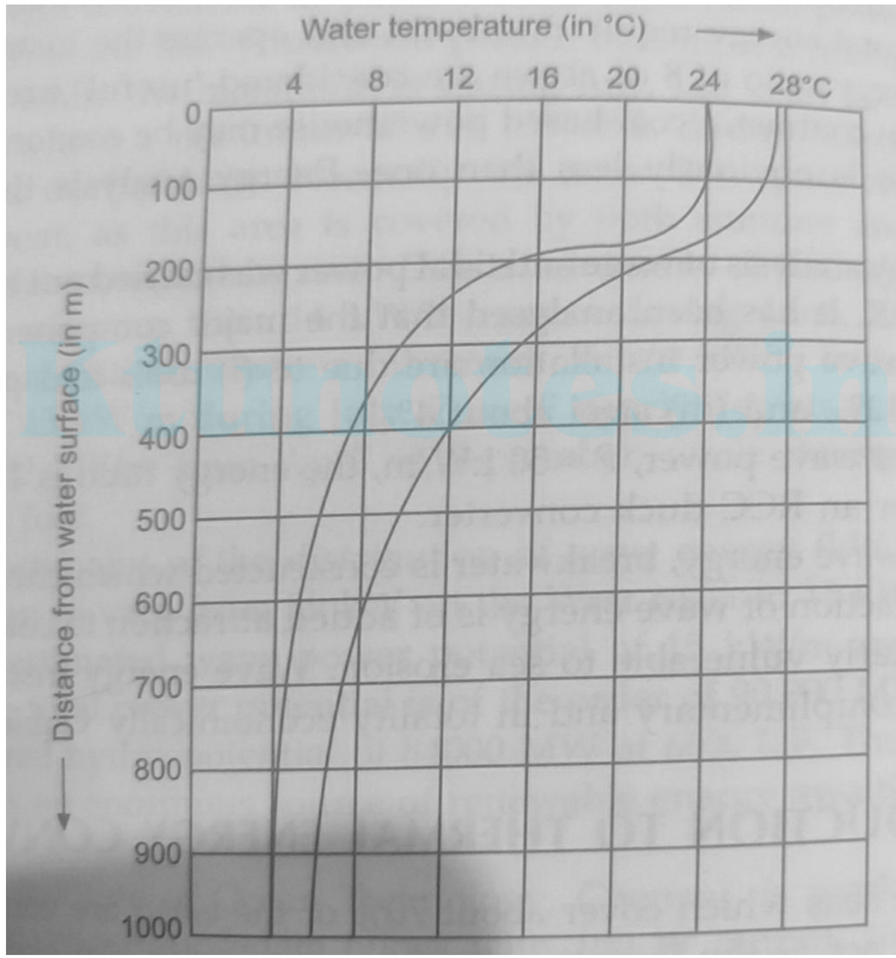
# Ocean Thermal Energy Conversion (OTEC)

- The oceans and the seas which cover about 70% of the earth are constantly receiving solar radiation and act as the largest natural solar collector.
- An ocean as a collector has an enormous storage capacity.
- Energy from the ocean is available in several forms, such as ocean thermal energy, wave energy and tidal energy.

- Ocean Thermal Energy Conversion (OTEC) is a new technology, needed to be harnessed especially in India where the coastline is about 6000 km.
- OTEC converts the thermal energy, available due to temperature difference between the warm surface water and the cold deep water, into electricity.
- According to MNRE, the overall potential of ocean energy in the country may be in excess of 50,000 MW.

# Working principle of OTEC system

- A temperature difference of about 20$^{o}$C between the warm surface water of the sea and cold deep water in equatorial areas between latitude 30$^{o}$ S and 30$^{o}$ N.
- Solar heat energy is absorbed by ocean water.
- Lambert's law of absorption- "Each water layer of identical thickness absorbs an equal fraction of light that passes through it."
- The intensity of heat decreases with the increase in water depth.


Water temperature (in °C)
4
8
12
16
20
24
28°C
0
100
200
300
400
500
600
700
800
900
1000
Distance from water surface (in m)

- The temperature at the surface changes slowly, then remains constant at a depth of about 200 m.
- Subsequently, the temperature decreases asymptotically and approaches a low value of about 4$^{o}$C at a depth of 1000 m.
- The difference in temperature between the surface and the deeper parts of the ocean is utilised to generate electrical energy.

- The basic process of OTEC is to bring the warm surface water and the cold water from a certain depth of the sea through pipes so as to act as heat source and heat sink for operating a heat engine.
- Three types of OTEC plants

(i) Closed

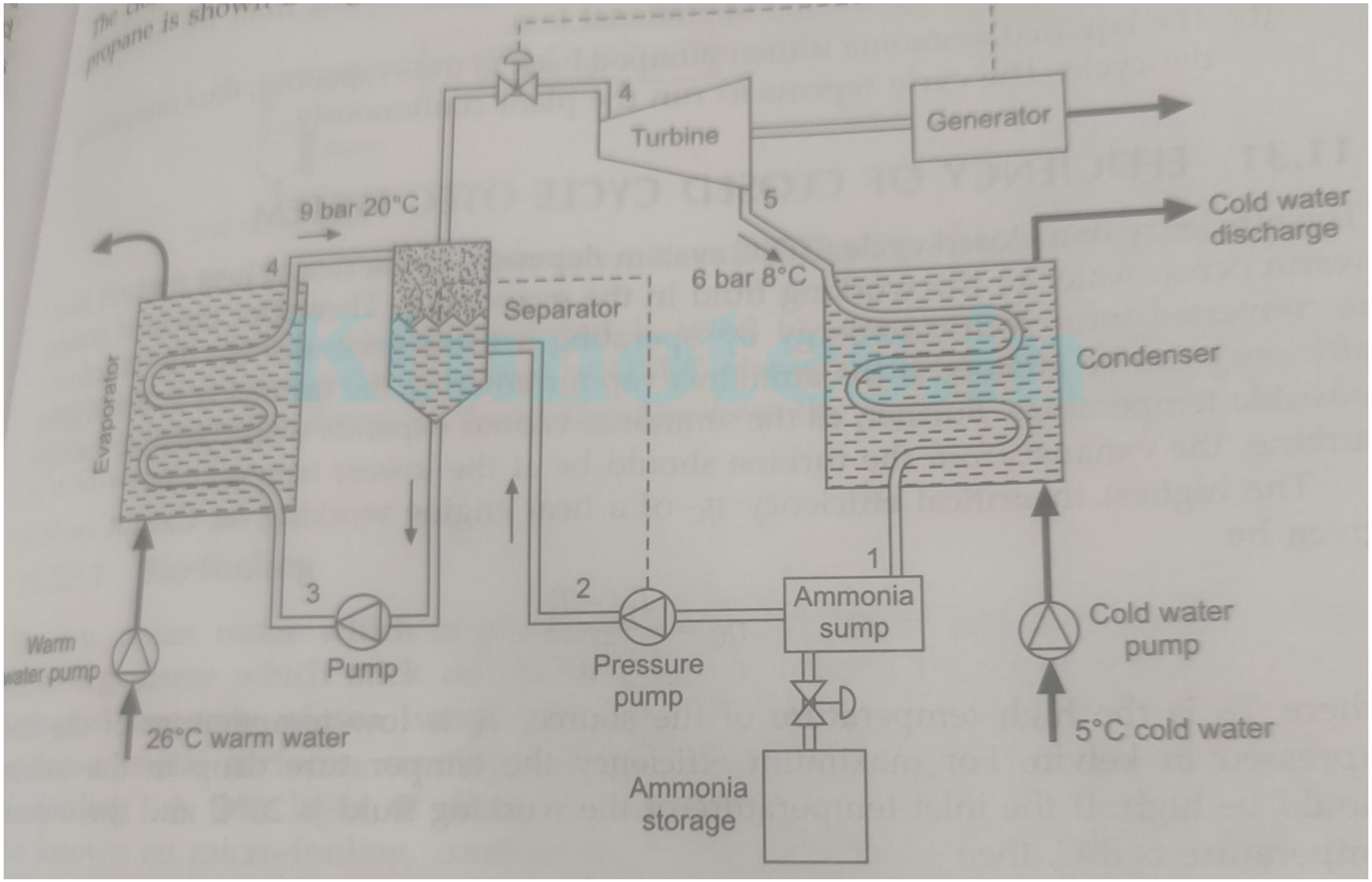
(ii) Open

(iii) Thermoelectric

# Closed Rankine cycle or Anderson closed cycle OTEC system

- Uses a low boiling point working fluid like ammonia or propane.
- Warm water from the surface which is at a temperature of about 26$^{o}$C is brought in one pipe, and cold water at a temperature of around 5$^{o}$C is brought in another pipe from a depth of about 1000 m.
- Two water pipes are used in conjunction with a working fluid to generate electric power.

# Closed Rankine cycle or Anderson closed cycle OTEC system



# Closed Rankine cycle or Anderson closed cycle OTEC system

The operational activities of the plant are:

(i) The warm sea water evaporates the liquid ammonia into vapour in a unit called an evaporator. This can be done because ammonia exists in the form of gas at the temperature corresponding to the surface sea water.

(ii) The liquid ammonia which is not evaporated collects in a unit known as separator, which again recirculates through the evaporator.

# Closed Rankine cycle or Anderson closed cycle OTEC system

(iii) The evaporated ammonia is the form of high pressure vapour is made to pass through a turbine where its pressure and temperature make the turbine to rotate, thus converting thermal energy to an electric generator produces electric power.

(iv) The ammonia vapour coming out of the turbine, which is now at the lower pressure than when it entered the turbine is condensed back into liquid ammonia by cooling it with the colder sea water brought up from the deep part.

# Closed Rankine cycle or Anderson closed cycle OTEC system

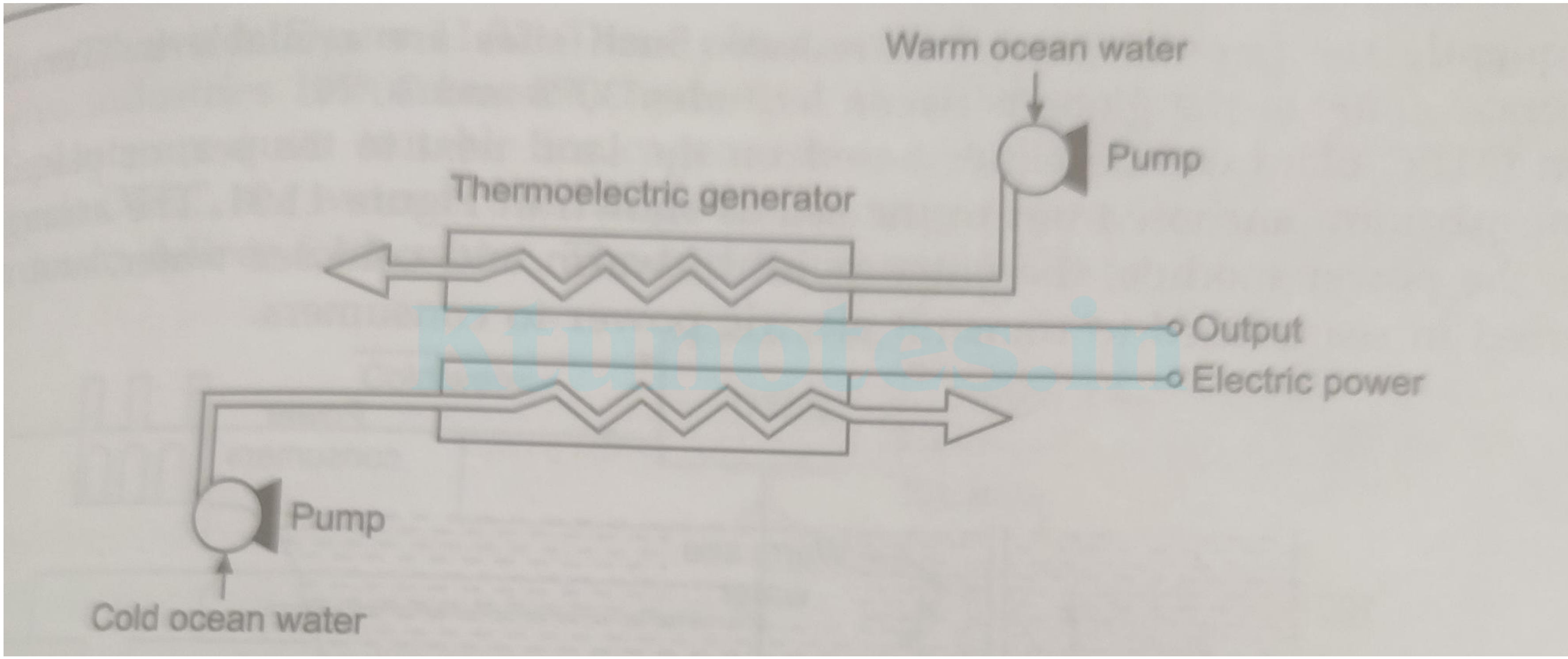
(v) The liquefied ammonia collects in an ammonia sump. After a few hours of operation, the makeup quantity of ammonia is added from the ammonia storage to make up for the operational loss.

(vi) The liquified amonia is then pumped back to the evaporator, thus completing the cycle. The cycle repeats to run the plant continuously.

# Thermoelectric OTEC

- Works based on thermoelectric principle.
- Semiconductors are used to design two separate packs covered by a thin thermal conducting sheet.
- Warm water from the surface of the ocean is circulated over one device and the cold water pumped from the depth of the ocean is allowed to flow over the other device.

# Thermoelectric OTEC



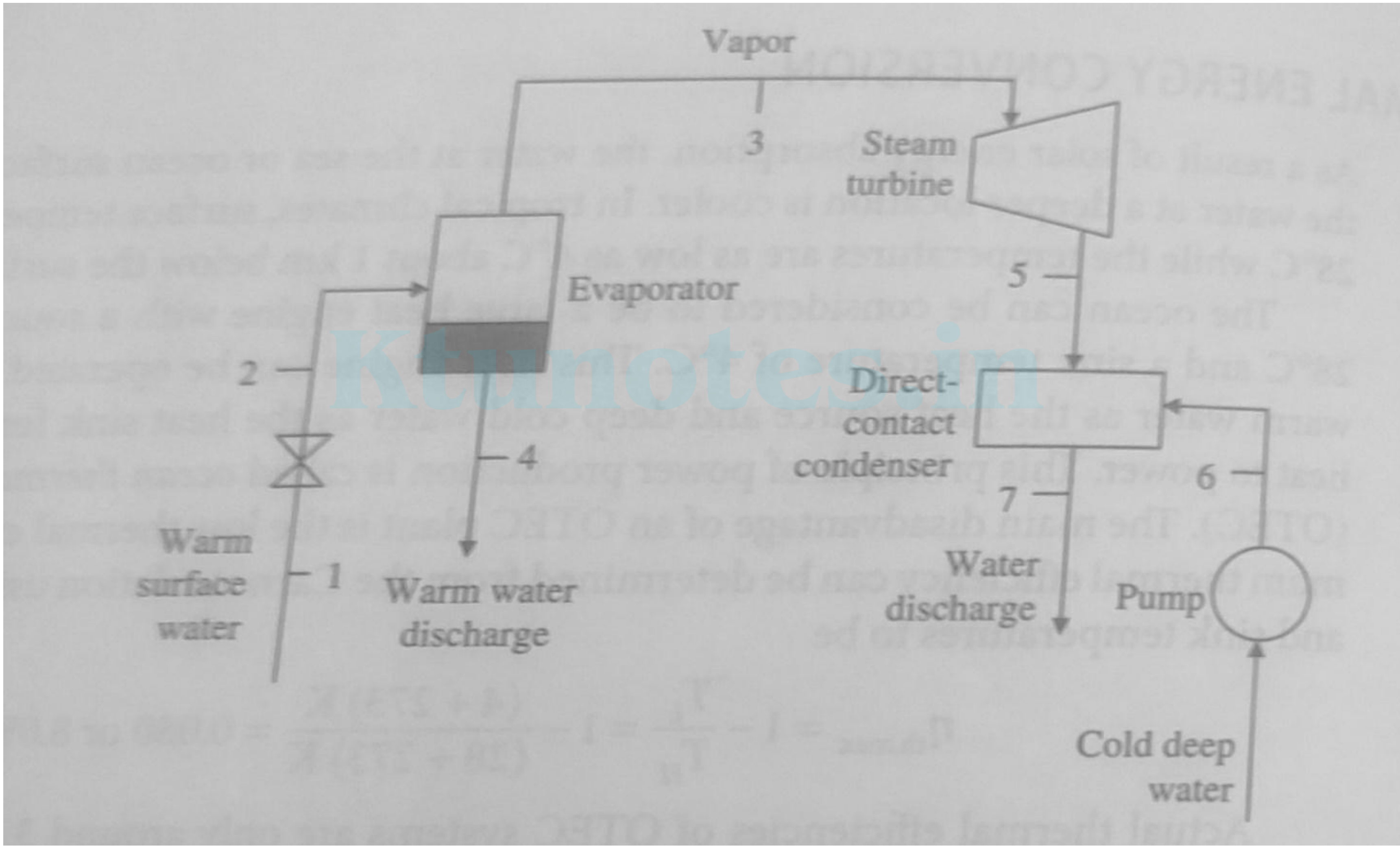
# Thermoelectric OTEC

- The temperature difference between these two water with the solid state semiconductor devices generates the electric power.
- A part of electric power generated in used to operate the pumps and other equipment.

# Open Cycle (Claude cycle) OTEC

- Similar to flash cycle of geothermal power plants.
- A chamber is maintained at a subatmospheric pressure by a vacuum pump.
- Warm surface water flows into this chamber, where its pressure is reduced.
- As the pressure of warm water decreases, its temperature also decreases, resulting in a liquid vapor mixture.

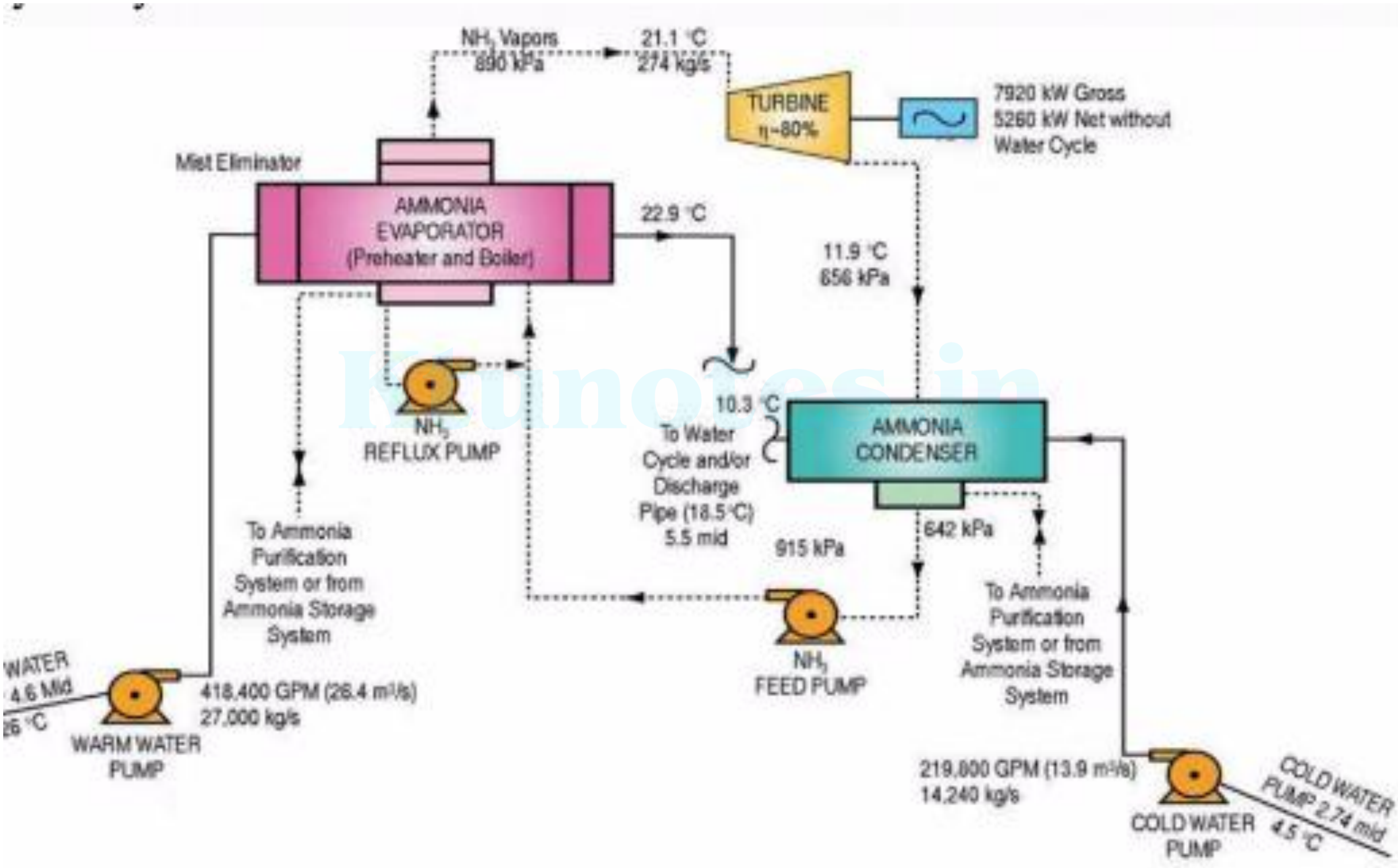
# Open Cycle (Claude cycle) OTEC



# Open Cycle (Claude cycle) OTEC

- Low pressure vapor is directed to a steam turbine while the liquid is discharged from the chamber.
- The vapor exits to a direct contact condenser, which is maintained at a much lower pressure.
- Cold deep water is supplied to the condenser by a pump, and mixing of this cold water with the vapor from the turbine outlet turns the vapor to the liquid, which is discharged.

# Hybrid cycle OTEC cycle



# Bio-fouling

- The raw ocean water which is pumped in for evaporator and condenser, contains micro-organisms which stick on the water side of both the heat exchangers.
- This biological impurities of sea water that deposits and grows on the evaporator and condenser metal surfaces, creating thermal resistance for heat transfer, is known as bio-fouling.

# Location of OTEC plants

- The selection of suitable site for an OTEC plant needs a temperature difference of about 20$^oC$ between the surface and the deep sea ocean water.
- If the temperature difference is higher the site becomes more suitable as it will increase the power output, consequently the per unit cost will reduce.
- Such sites are available in ‘Torrid and Temperature zone’ of the globe between latitudes 30$^o$S and 30$^o$N.

- Ocean Thermal Energy Conversion (OTEC): Principle of OTEC system, Methods of OTEC power generation – Open Cycle (Claude cycle), Closed Cycle (Anderson cycle) and Hybrid cycle (block diagram description of OTEC)

# Wave power technologies

1. Oscillating water column technology

- Transferring the energy of wave water to air and using the compressed air to drive a turbine.
- Water moves into a hollow container by the wave motion. This compresses air that was in the container.
- The compressed air drives the turbine, which is connected to a generator where electricity is produced.

- When the wave moves in the opposite direction, air fills the container from the top, which is open to the atmosphere.
- Air flows through the turbine from both sides, depending on whether the device is breathing in or out. The process is repeated with the next wave.
- The system uses special rotor geometry so that there is no need to change the blade angles or the direction of rotation.

- These systems must be large , and many of them should be installed to produce significant amount of electricity.
- Oscillating water column technology has been installed off the coast of western Scotland.

- Oscillating water column technology can be applied in three types of coastal wave power plants.

1. Shoreline power plants
2. Near-shore power plants
3. Breakwater power plants

# What is Geothermal Energy?

- Geothermal energy is defined as heat from the Earth. It is a clean, renewable resource that provides energy around the world.

- It is considered a renewable resource because the heat emanating from the interior of the Earth is essentially limitless.

- **Geothermal is a natural form of nuclear power, as it originates from radioactive decay.**

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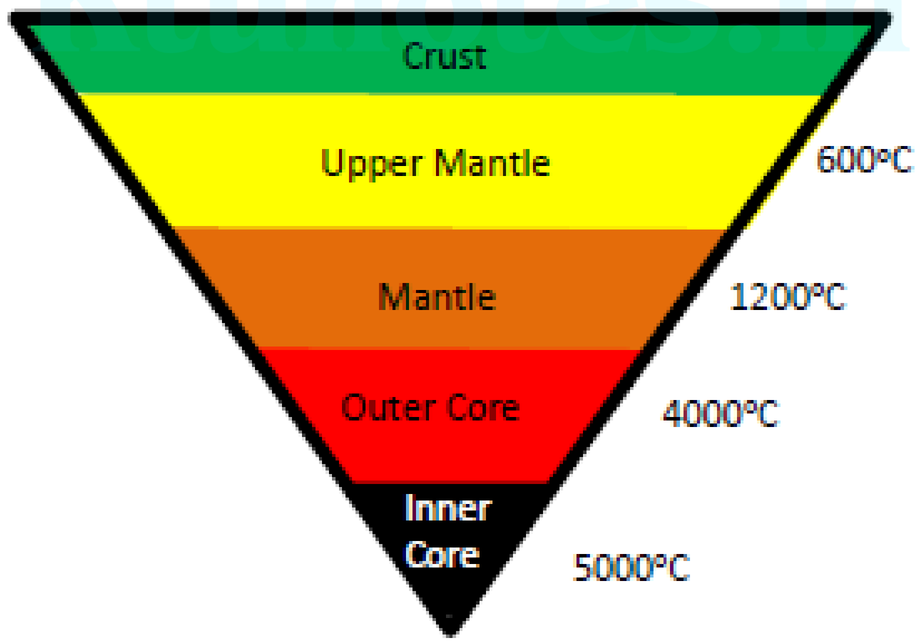
# Harnessing Geothermal

- Geothermal power emits from earth at a rate of $44 \times 10^{12}$ *W*. This is more than double the total power consumption of the world.
- The Earth's crust acts as a massive insulating "blanket" that traps this heat deep under the surface. Thus, the crust must be pierced to release this heat.
- Unfortunately, this power is too spread out to effectively use it all.
- The distribution of geothermal energy, however, is not uniform. Certain regions have an enormous geothermal resource
  - Where the crust is thin or fractured, as at the edges of tectonic plates, volcanoes, geysers and hot springs deliver this energy to the surface.

# Origin of Geothermal Power

Geothermal energy originates from the Earth's core, which is estimated to have a temperature of about 5000°C. This nearly constant temperature is possible because of continuous radioactive decay, compression, and because the core is very well insulated.



# Geothermal Sources

- Hydro thermal
  - Vapor dominated systems
  - Liquid dominated systems
  - Hot water fields
- Geopressured
- Hot dry rock or petrothermal
- Magma resources
- Volcanoes

# Geothermal Sources

- Hot Water Reservoirs
  - Heated underground water pools, very large in magnitude in the U.S.; not appropriate for electricity but can be useful for space heating
- Natural Steam Reservoirs*
  - e.g. The Geysers power plant (California). Highly desirable type of resource for direct generation of electric, though very rare
- Geopressured Reservoirs*
  - Hot, *superheated* brine solution saturated with natural gas. Useful for both its heat content and natural gas
- Hot Dry Rock
  - Hot rock can be used to heat a working fluid is forced through a series of man-made channels and cycled. No technology yet exists to do this
- Hot Molten Rock (Lava)
  - No technology yet exists to extract heat energy from lava

# Estimated U.S. Geothermal Resources

| Resource Type | Total Resource (QBtu) | Potentially Usable Resource (QBtu) |
|---|---|---|
| Hot Water | 12,000 | 6,000 |
| Natural Steam | 180 | 45 |
| Geopressurized | 73,000 | 2,400 |
| Hot Rock | 1,410,000 | 14,100 |
| Lava | 3,500 | 35 |

* The U.S. consumes 98 QBtu of energy per year

# Geothermal power generation

1. Liquid dominated resource

(a) Flash steam system

(b) Binary cycle system

2. Vapour dominated resource

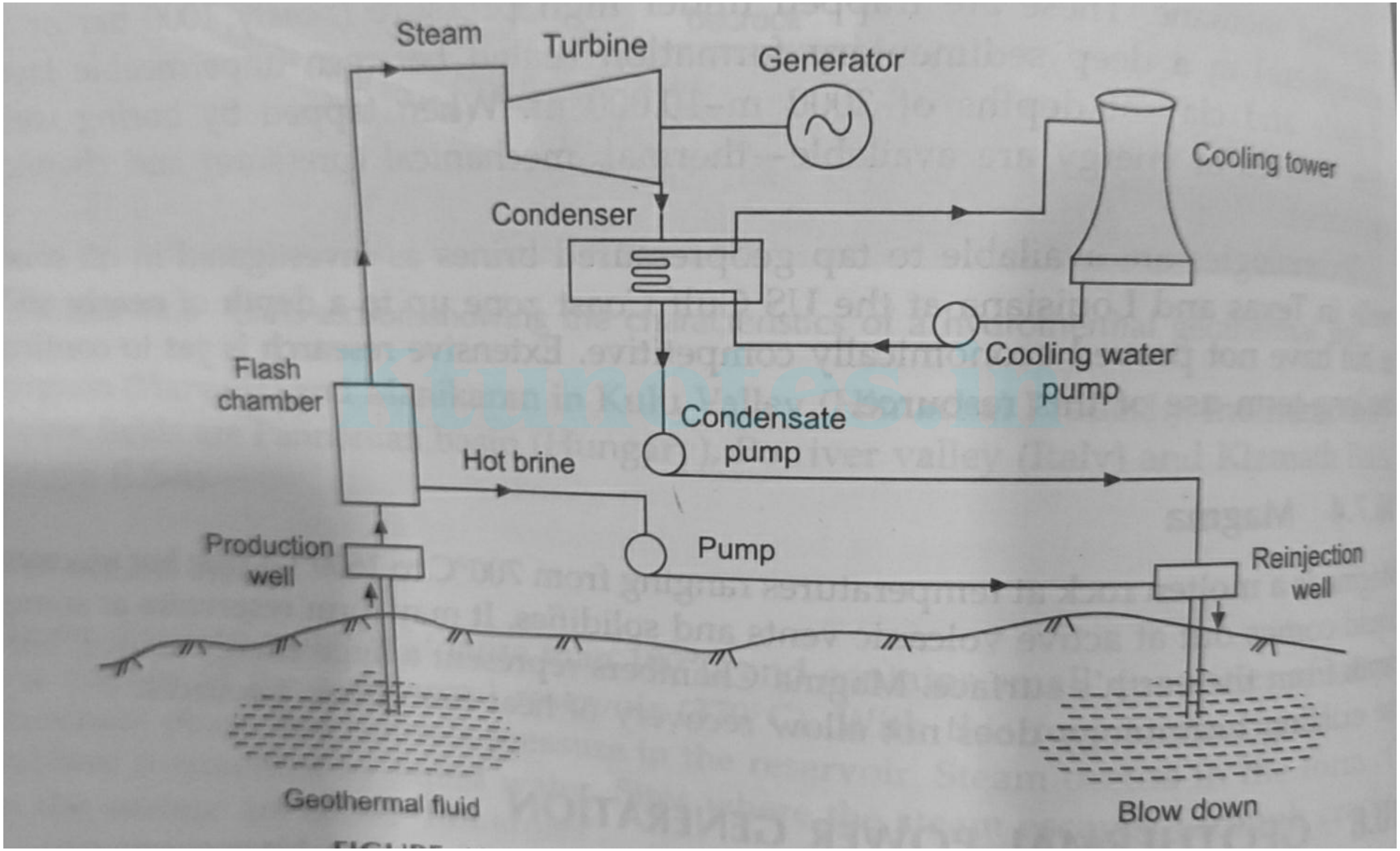
# Liquid dominated resource

- Geothermal fluid is either available from natural outflow or from a bored well.
- The drilling cost increases greatly with depth and the technically viable depth is 10 km.

# Flashed steam system

- The choice of geothermal power plant is influenced by brine characteristics and its temperature.
- For brine temperature more than 180$^oC$, the geothermal fluid is used.
- This flashed steam is suitable for power generation.
- Geothermal fluid is a mixture of steam and brine, it passes through a flash chamber where a large part of the fluid is converted to steam.

# Flashed steam geothermal power plant



# Flashed steam system

- Dry saturated steam passes through the turbine coupled with the generator to produce electric power.
- Hot brine from flash chamber and turbine discharge from the condenser are reinjected into the ground.
- Reinjection of the spent brine ensures a continuous supply of geothermal fluid from the well.

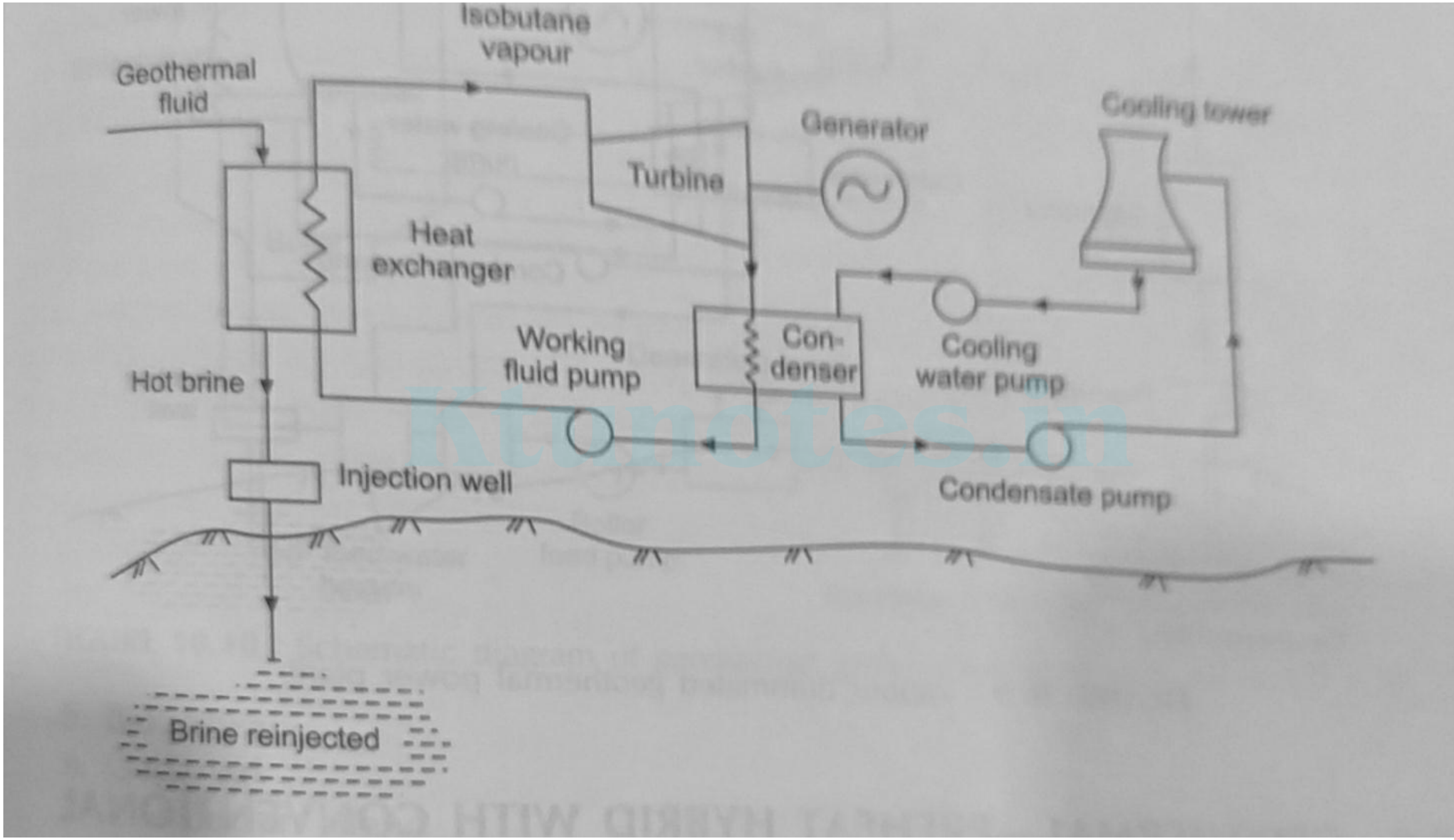
# Flashed steam system

- Commercially available turbogenerator units in the range of 5-20 Mwe are in use.
- To improve the total efficiency of the system, hot water is utilised for poultry farming in cold regions.

# Binary cycle system

- A binary cycle is used where geothermal fluid is hot water with temperature less than 100$^{o}$C.
- This plant operates with a low boiling point working fluid (isobutane, freon) in a thermodynamic closed Rankine cycle.
- The working fluid is vapourised by geothermal heat in a heat exchanger.

# Binary cycle geothermal power plant



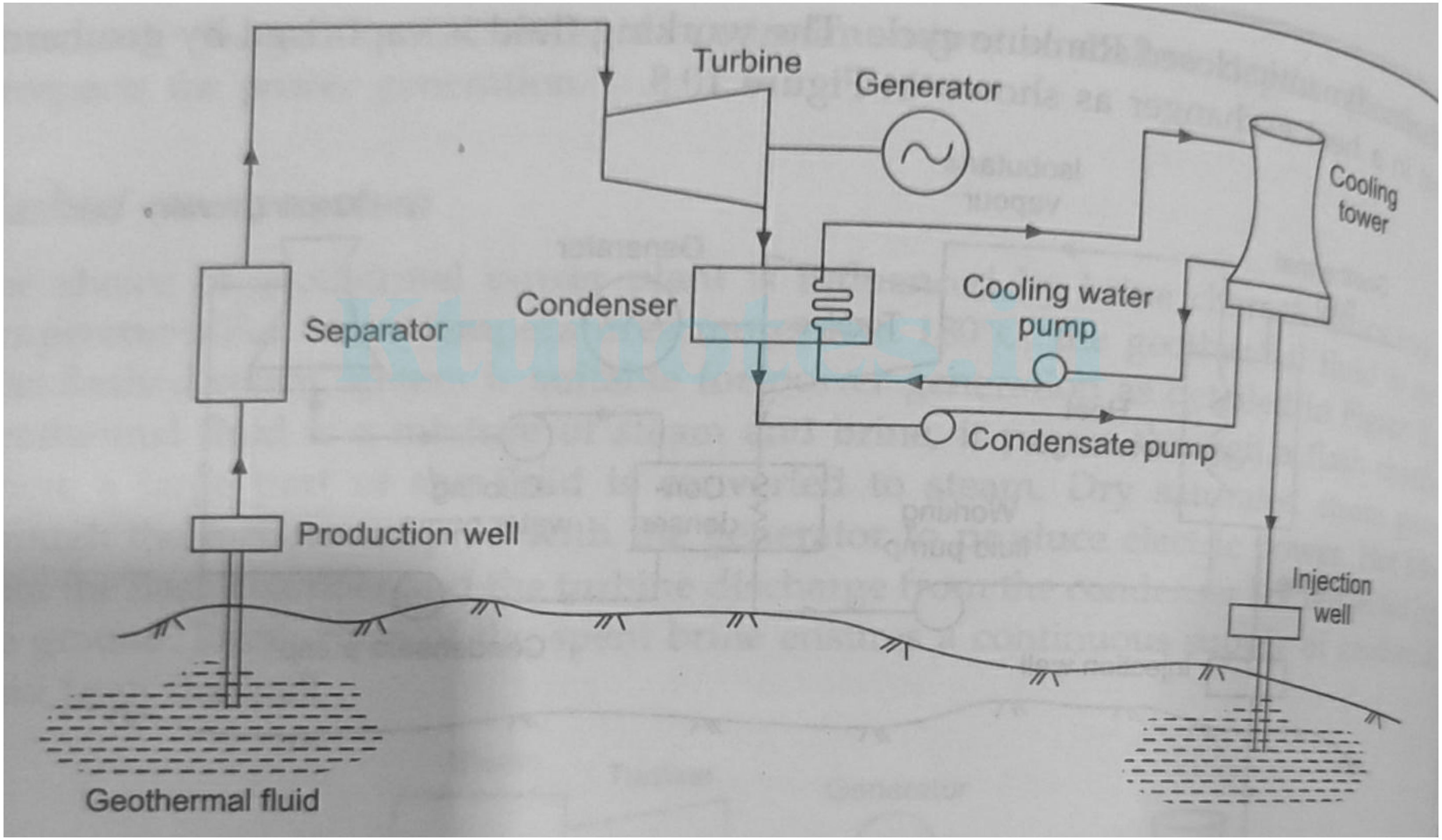
# Binary cycle system

- Vapour expands as it passes through the turbine coupled with the generator.
- Exhaust vapour is condensed in a water cooled condenser and recycled through a heat exchanger.
- Power plants of 11 MW in California and 10 MW in Raft River Idaho USA operate on binary cycle.

# Vapour dominated geothermal Electric power plant

- In a vapour dominated plant, steam is extracted from geothermal wells, passed through a separator to remove particulate contents and flows directly to a steam turbine.
- Steam that operates the turbine coupled with the generator is at a temperature of about 245$^{o}$C and pressure 7 kg/cm$^{2}$ (7 bar) which are less than those in conventional steam cycle plants (540$^{o}$C and 130 kg/cm$^{2}$).

# Vapour dominated geothermal power plant

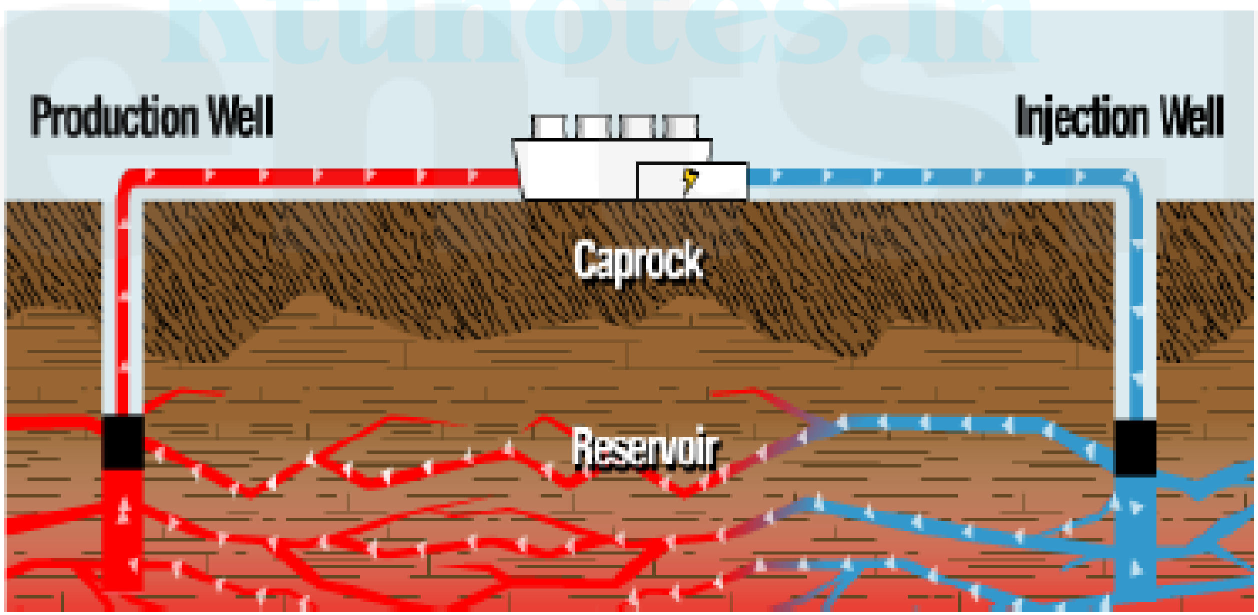


# Vapour dominated geothermal power plant

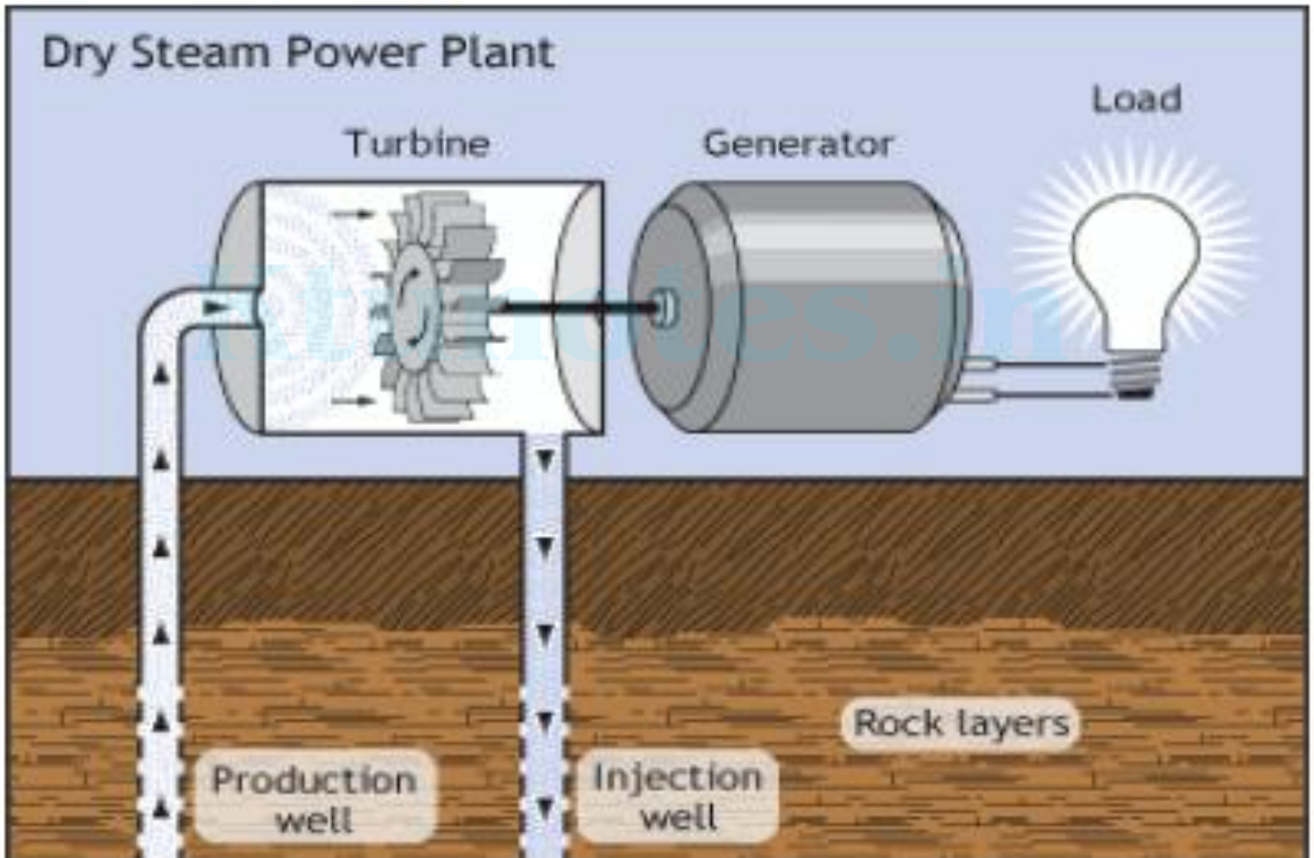
- Exhaust steam from the turbine passes through a condenser and the water so formed circulates through the cooling tower.
- It improves the efficiency of the turbine and controls environmental pollution associated with the direct release of steam into the atmosphere.
- Waste water from the cooling tower sump is reinjected into the geothermal well to ensure continuous supply.

# Geothermal Power Plants

- There are three types of geothermal power plants
  - Direct Dry Steam Plants
  - Flash Cycle Plants
  - Binary Closed Cycle Plants



# Direct Dry Steam Power Plant

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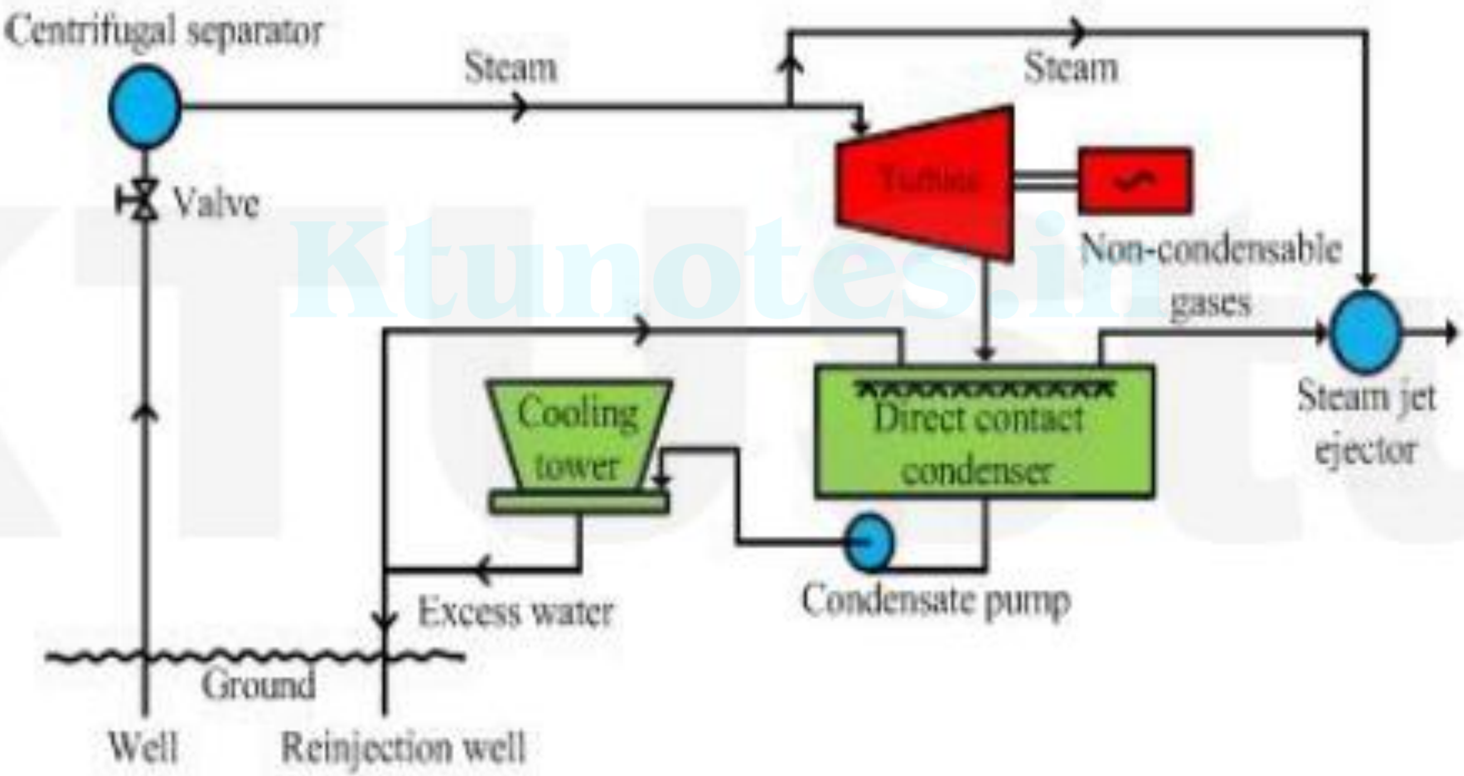
# Direct Dry Steam Power Plant

- The oldest type of Geothermal power plant used.
- Geothermal reservoir containing pure steam is required.
- Pure dry steam drives turbine.
- Very rare type of geothermal power plant.
- Operating at California, Italy, and Japan.

# Dry Steam Power Plant

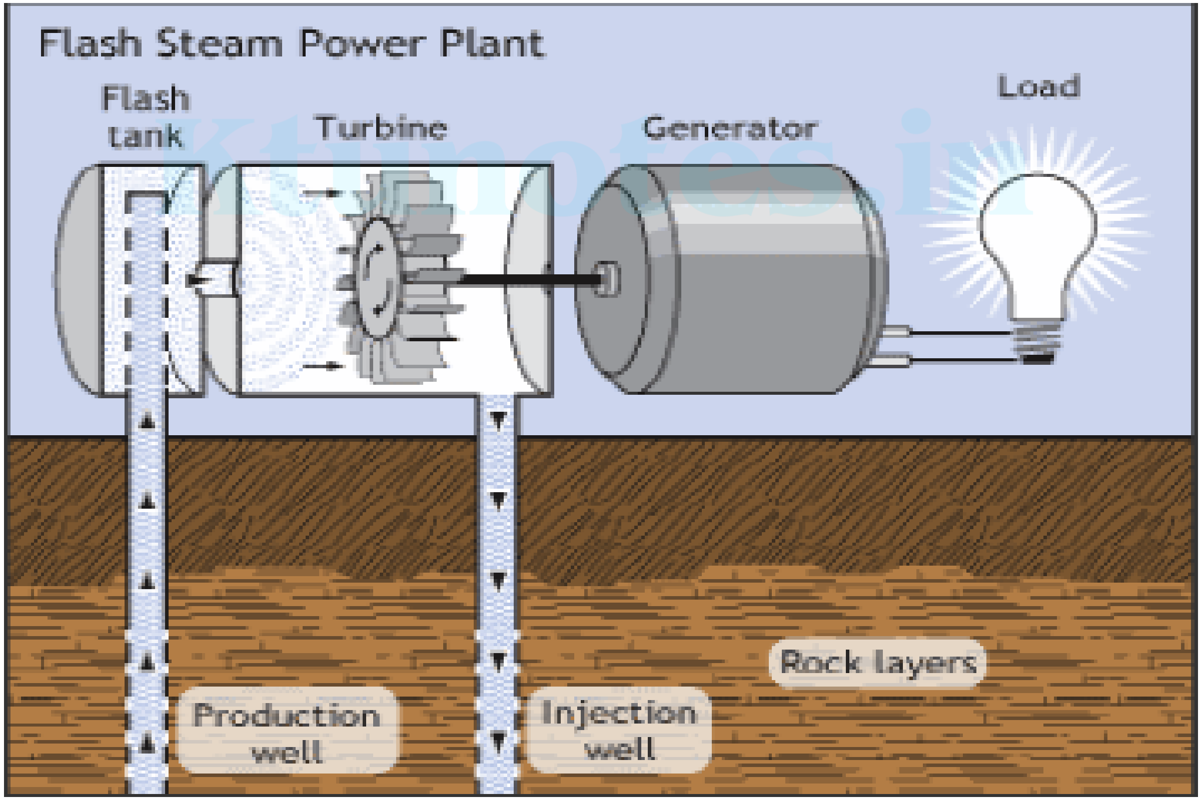



*Vapour dominated power plant*

# The Geysers (California)

# Flash Cycle Plants

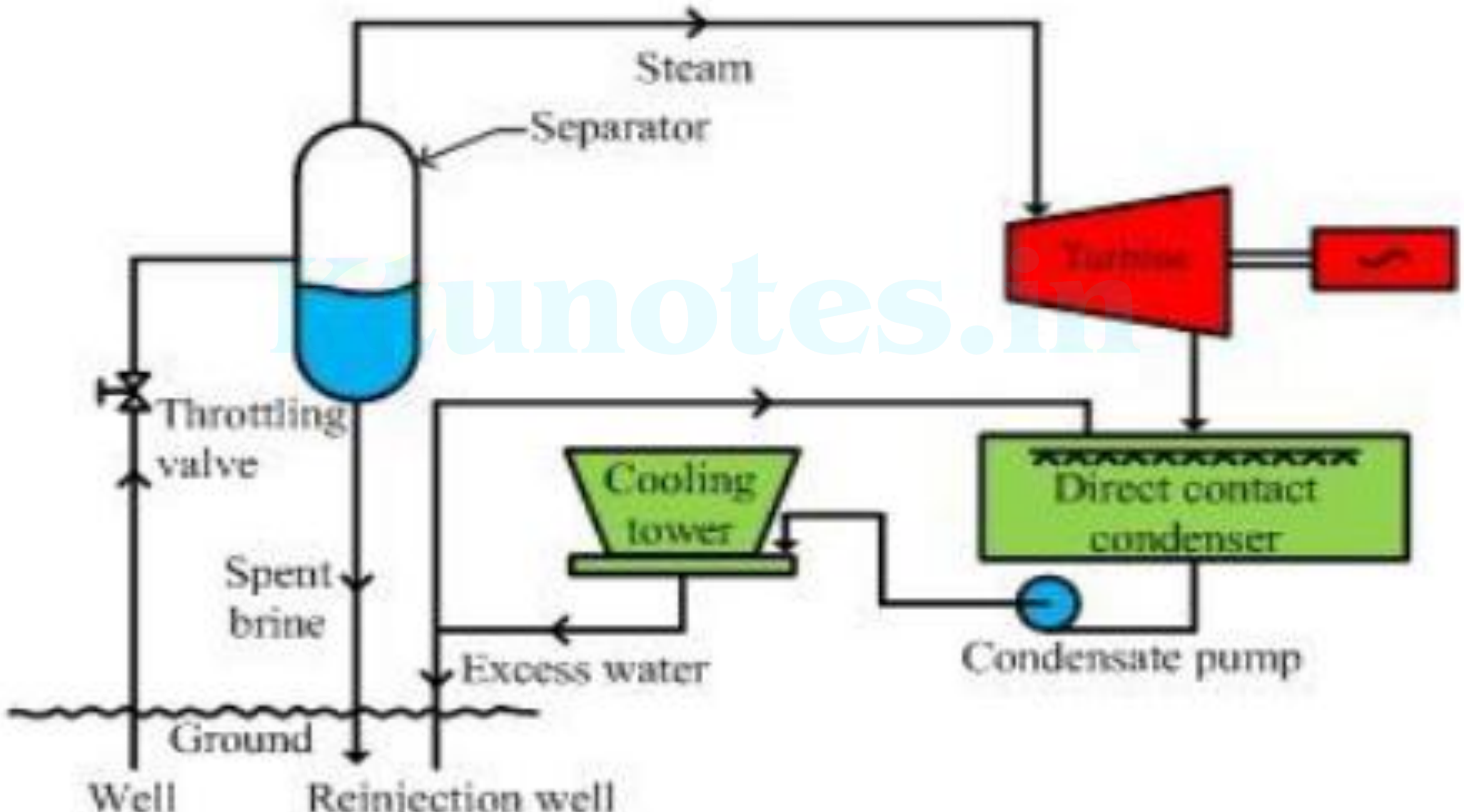
Uses superheated brine. When the brine enters a low pressure chamber called a flash tank, it instantly vaporizes (flashes).



# Flash Cycle Plants

- Commonly used geothermal power plant.
- Geothermal reservoirs containing both hot water & steam is required.
- Pressure changing system is required.
- Operating at Hawaii, Nevada, Utah & some other places

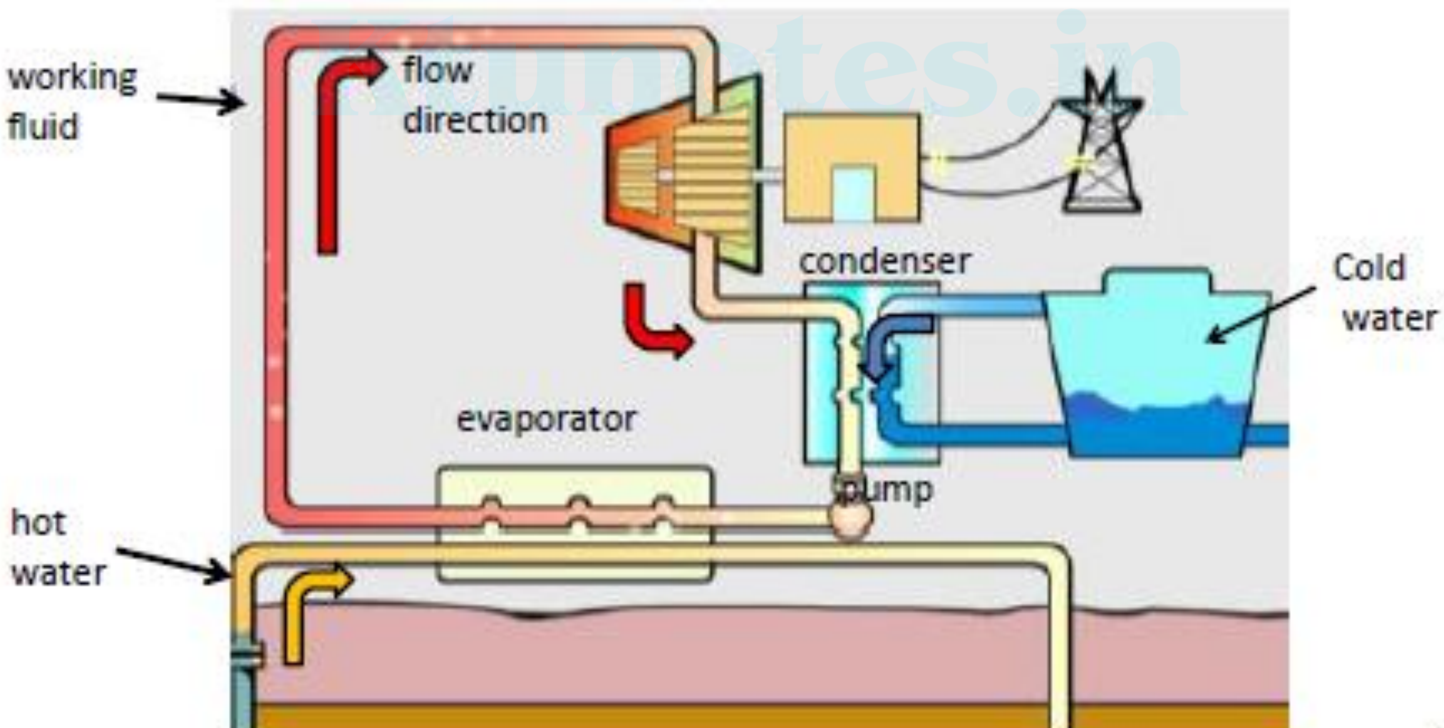
# Flash Cycle Plants




*Liquid dominated flash steam system*

# Binary Closed Cycle Plants

Binary closed cycle plants use a working fluid (i.e. Freon-12) to spin a turbine. The working fluid cycles through a heat exchanger where it is evaporated by hot water from a geothermal reservoir.



# Binary Closed Cycle Plants

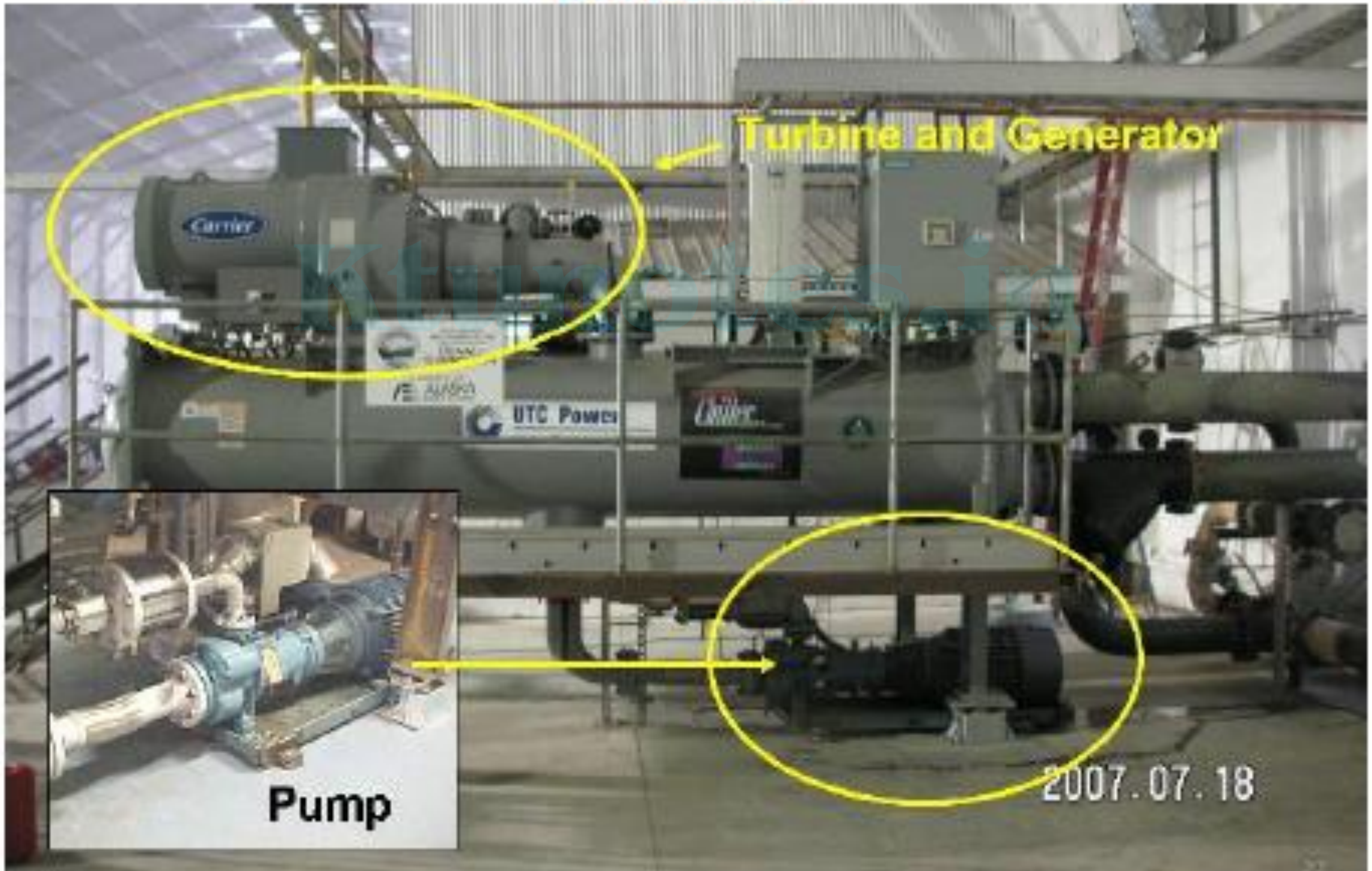
- Does not use steam directly to spin turbines.
- Only the heat of the underground water is used.
- Vapourized hydrocarbons are used to spin the turbine.
- Hydrocarbons having lower boiling point such as isopentane, isobutane and propane can be used.
- No harmful gas is emitted to the atmosphere because the underground water is never disclosed to outside.
- This's the worldwide accepted power plant.

# Binary Closed Cycle Plants

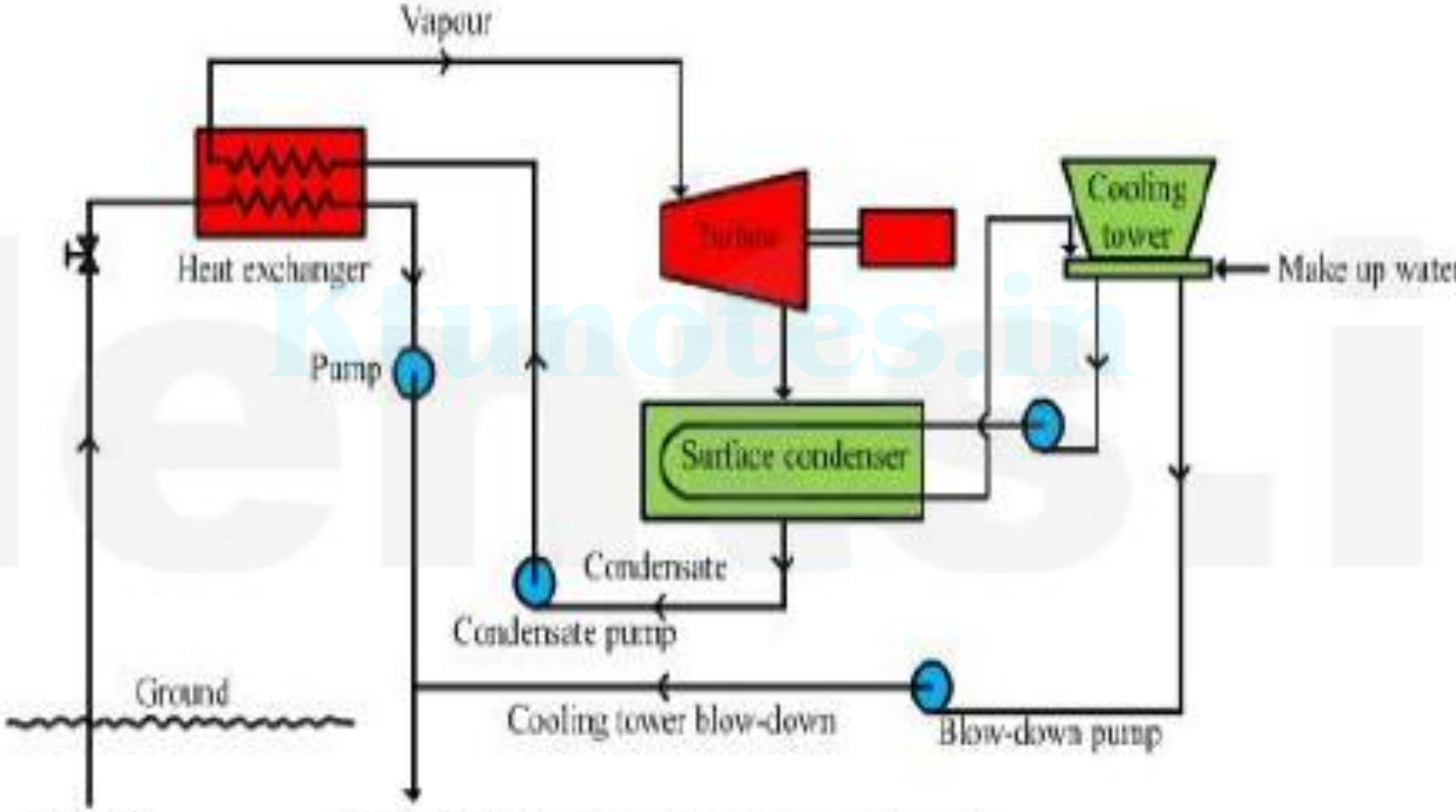
- Binary cycle plants are the most useful because it is not necessary for the water to reach the extreme temperatures that are experienced with dry steam and flash plants.
  - The water in a binary cycle plants needs only to be above the boiling temperature of the working fluid

- Considering that most geothermal water is of moderate temperature (> 400°F), these are the most useful and most viable types of geothermal plants.

# Binary Closed Cycle Turbine At Chena Power Plant in Alaska



# Binary Closed Cycle Plants




*Liquid dominated binary cycle system*

# Geothermal Energy in India

# Geothermal Energy in India

- Geothermal provinces are estimated to produce 10,600 MW of power (experts are confident only to the extent of 100 MW)
- Geothermal provinces in India: the Himalayas, Sohana, West coast, Cambay, Son-Narmada-Tapi , Godavari, and Mahanadi.
- Reykjavík Geothermal will assist Thermax to set up a pilot project in Puga Valley, Ladakh (Jammu & Kashmir).
- First operational commercial geothermal power plant is likely to come up in AP with a capacity of 25 MW by Geosyndicate Pvt Ltd.

# Advantages of Geothermal

- Geothermal energy is a renewable energy source with virtually limitless supply.
- Geothermal energy is *relatively* clean (Produces 12% of GHG emission of fossil fuel plants)
- Geothermal energy can be used for cooling and heating homes.
- Not subject to the same fluctuations as solar or wind
- Smallest land footprint of any major power source
- Inherently simple and reliable and could be built underground.
- Can provide base load or peak power
- Already cost competitive in some areas (~$0.07 per kWh)
- Massive potential for the utilization of untapped sources
- New technologies show promise to utilize lower water temperatures.

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# Disadvantages of Geothermal

- High upfront costs associated with exploration and drilling
- Finite lifetime of useful energy production
  - Continuous drop in thermal output overtime
  - Once the thermal energy of a well is tapped, it requires a "recharging" period that can take several years.
- Very location specific (e.g. Iceland)
- There are significant volumes of greenhouse gases and toxic compounds such as hydrogen sulfide that are released when geothermal reservoirs are tapped
  - Foul smelling gases
  - Pumps used to circulate working fluid consume fossil fuel
- **Earthquakes induced by fracking.**

# Ocean Thermal Energy Conversion (OTEC)

- The world's oceans constitute a vast natural reservoir for receiving and storing heat energy from the sun.

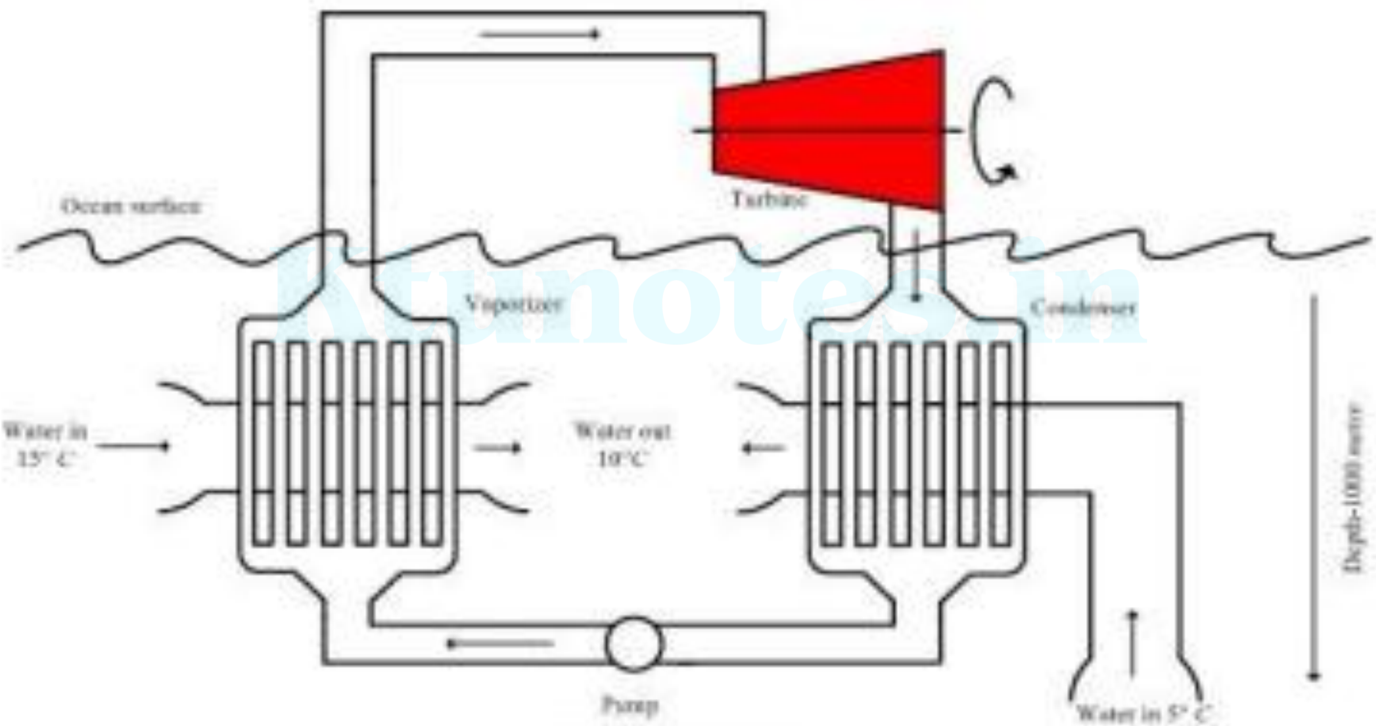
- Nearly 75% of the surface area of Earth is water. Due to the high heat capacity of water, the water near the surface is maintained at significant higher temperatures than water at greater depth.

- It is possible to extract energy from the oceans through the use of heat engines in order to exploit the temperature differences between warm surface water and the cold, deep water.

# Closed-Cycle OTEC System

- Closed-cycle systems have been considered for OTEC.
  - In such a system, a low heat capacity working fluid passes through a heat exchanger (evaporator) which
  - The vapor passes through an expansion valve and forces the rotation of a turbine
  - Cold water from the depths cools the condenses the working fluid via heat exchanger, and the process repeats.

# Ocean Thermal Energy Conversion




*Ocean thermal energy*

Solar heating of upper layer of ocean water combined with earth's rotation produces large convection currents while the deep water remains relatively cold. These temperature difference could be used to generate electrical energy.

# Ocean Thermal Energy

- Earlier OTEC systems had an overall efficiency of only 1-3% (theoretical max. efficiency lies between 6-7%), however newer designs operate closer to the theoretical maximum efficiency.
- Based on closed Rankine cycle with ammonia as the working fluid. Relies on temperature difference between deep sea water (7°C) and water surface (28°C).
- It consists of a vaporizer, turbine generator, condenser and pump. A low boiling point liquid (ammonia/R134a), is fed to the vaporizer as working fluid. The upper layers of ocean water heated by solar energy flows through the vaporizer.
- As a result, ammonia evaporates and flows to the turbine at high pressure and propels it. Later, the low pressure exit ammonia vapour passes through a condenser and is condensed to liquid ammonia.
- A large dia. intake pipe, submerged in the ocean for a depth of 1 kilometre or more, brings cold water to the condenser. liquid ammonia is then pumped back to the evaporator and the cycle repeats thereafter.
- In India, a floating 1 MW plant is commissioned at south east of Tuticorin, where an ocean depth of 1200m is available from 40 km off the main land.

# Ocean Thermal Energy

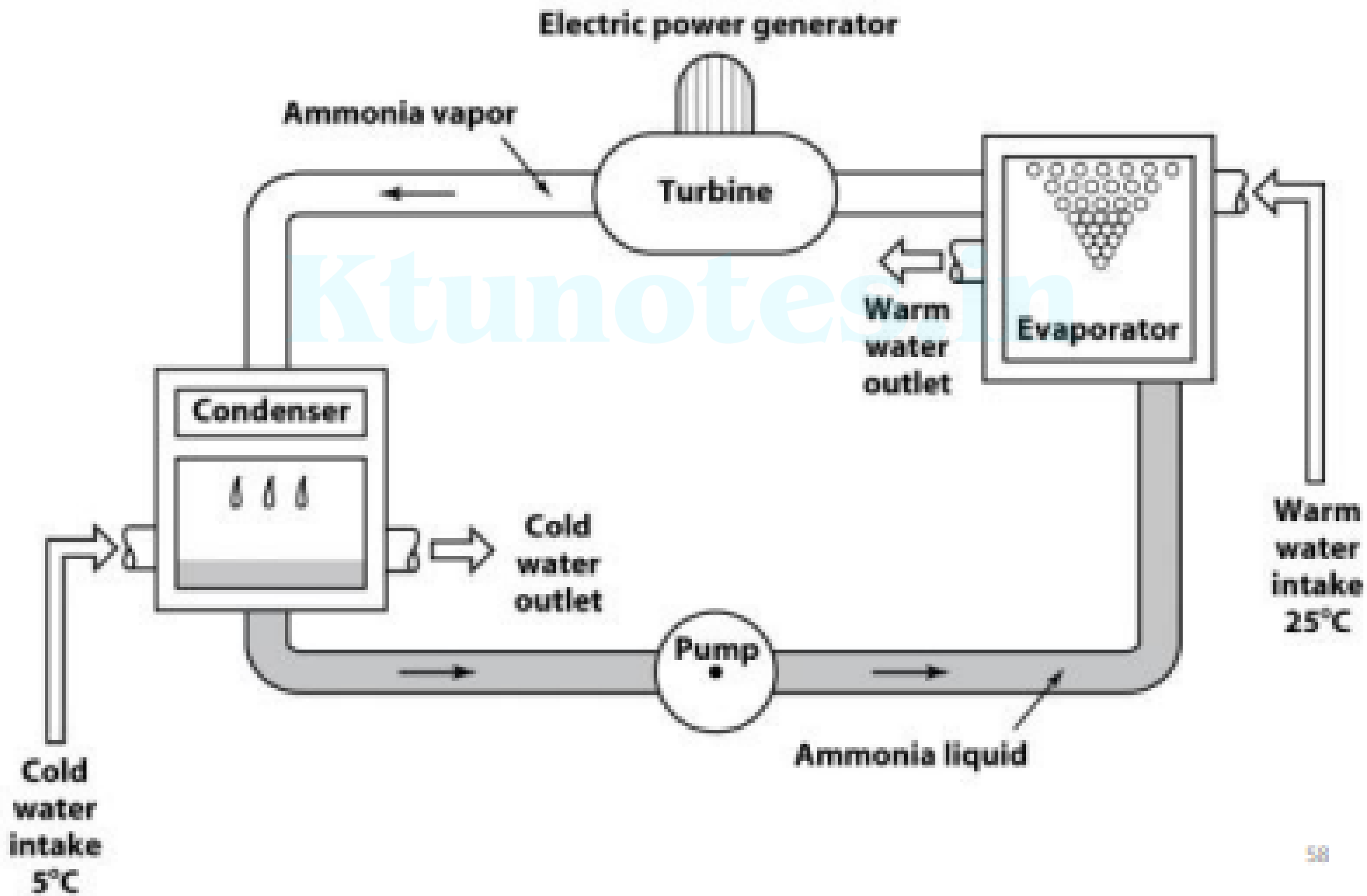
***Advantages:***

- It is steady and can be operated continuously.
- No waste products are involved.
- It has simple assembly and fewer accessories.

***Disadvantages:***

- Installation, maintenance and power transmission costs are high.
- Low overall efficiency.
- High pumping costs.

# Ocean Thermal Energy

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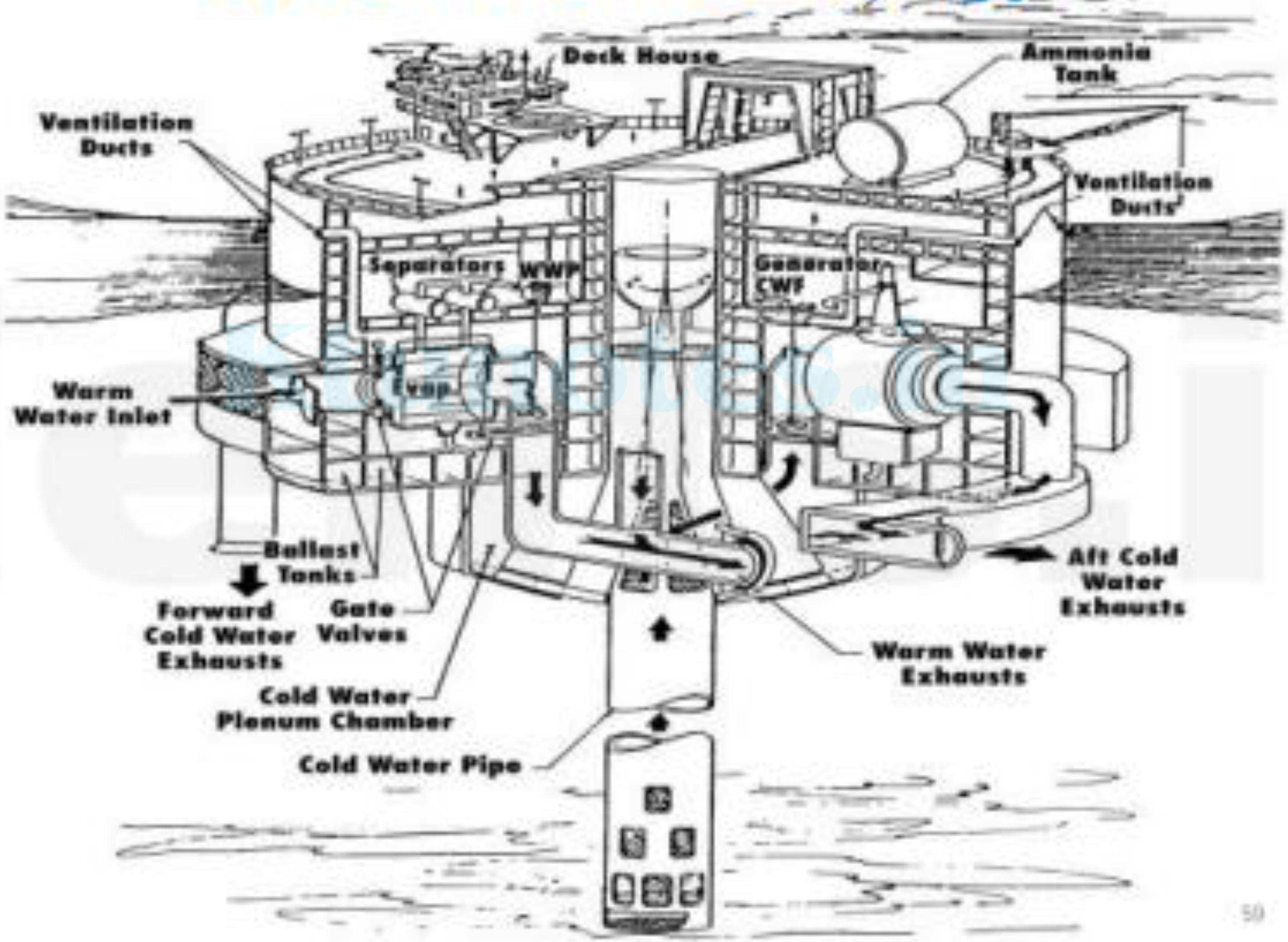
# Ocean Thermal Energy



# Wave Energy

Where does wave energy originate?

- Differential warming of the earth causes pressure differences in the atmosphere, which generate winds.
- As winds move across the surface of open bodies of water, they transfer some of their energy to the water and create waves



The amount of energy transferred and the size of the resulting wave depend on

- the wind speed
- the length of time for which the wind blows
- the distance over which the wind blows, or fetch

Therefore, coasts that have exposure to prevailing wind direction that face vast expanses of open ocean have the greatest wave energy levels.

# What is Wave Energy?

- Some of the kinetic (motional) energy in the wind is transformed into waves once the wind hits the ocean surface.
- Wind energy ultimately forms due to solar energy and its influence on high and low pressure.
- The density of the energy that is transported under the waves under the ocean surface is about five times higher compared to the wind energy 20 meter (about 65 feet) above.
- In other words, the amount of energy in a single wave is very high.

# Wave Energy Technologies

- Waves retain energy differently depending on water depth
  - Lose energy slowly in deep water
  - Lose energy quickly as water becomes shallower because of friction between the moving water particles and the sea bed
- *In order to extract this energy, wave energy conversion devices must create a system of reacting forces, in which two or more bodies move relative to each other, while at least one body interacts with the waves.*
- Wave energy conversion devices are designed for optimal operation at a particular depth range.

# Classification of wave power plants

Depending on the location

- Off shore or deep water
- Shoreline plants

Depending on the position w.r.t sea level

- Floating
- submerged
- partly submerged

*Depending on the actuating motion used in capturing wave power.*

- *Heaving float type*
- *Oscillating water column type*
- *Surge devices*

# Wave Energy Technologies

Therefore, devices can be characterized in terms of their placement or location.

- At the shoreline
- Near the shoreline
- Off-shore

➢ The availability of wave power at deep ocean sites is 3-8 times that of adjacent coastal sites. However the cost of construction, operation and transmission is large.

➢ Shore line devices are relatively easier to maintain and install.

➢ One wave energy conversion system that has proven successful at each of these locations is the **OSCILLATING WATER COLUMN**.

# On-shore versus Off-shore

In spite of the success of this technology in an on-shore application, most wave energy experts agree that off-shore or near-shore devices offer greater potential than shoreline devices.

## On-shore technologies

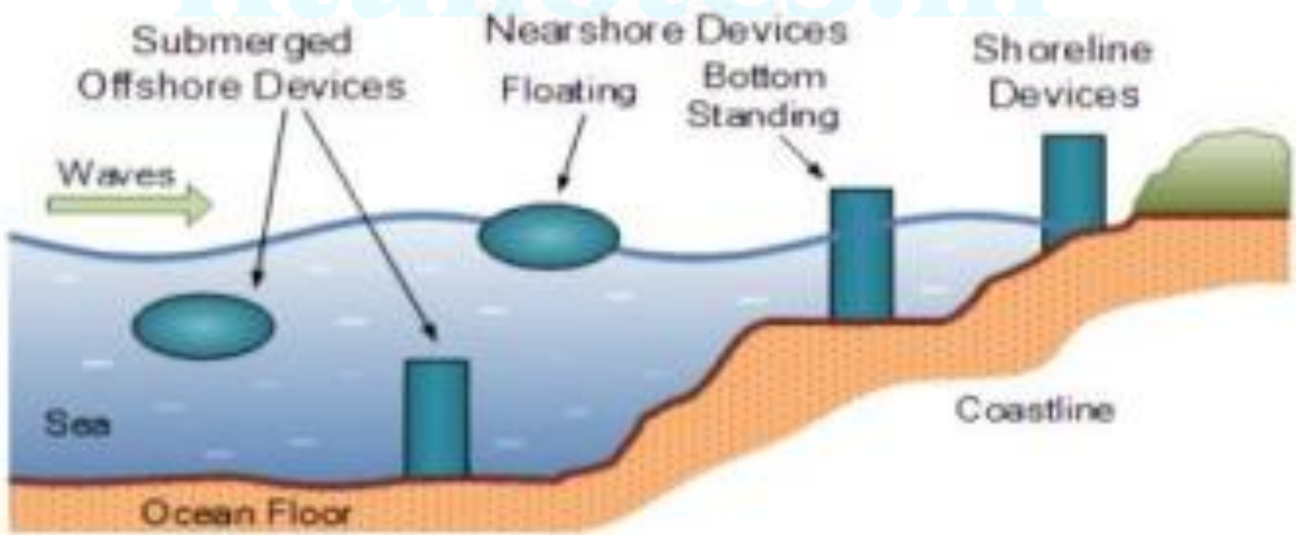
| Advantages | Disadvantages |
|---|---|
| • Easier to access for construction and maintenance<br>• Less installment costs and grid connection charges<br>• Could be incorporated into harbor walls or water breaks, performing a dual service for the community. | • Limited number of suitable sites/high competition for use of the shoreline<br>• Environmental concerns for on-shore devices may be greater<br>• Much less energy available to on-shore devices because water depth usually decreases closer to the shore |

# Classification of wave power plants

Depending on the position w.r.t sea level

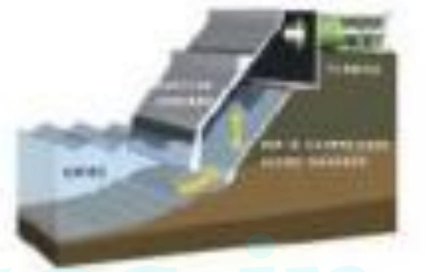
- Floating
- submerged
- partly submerged





# Advanced types of wave power

- The Oscillating Water Column, water works as a piston to pump air and drive a turbine to generate power.





- The Pelamis Machine floats on the surface of the water. The rolling motion of the waves generates electricity.

- The Energy buoys are anchored to the ocean floor and generating electricity by the bobbing up and down.

# Classification of wave power plants

Depending on the actuating motion used in capturing wave power.

- Heaving float type
- Oscillating water column type
- Surge devices

# Heaving float or buoy systems

It utilizes a large float/buoy placed on ocean's water surface that rise and fall with the waves.

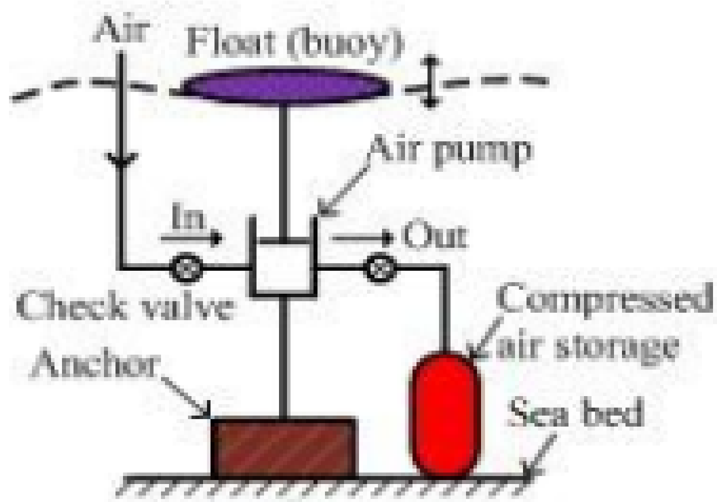
The resulting vertical motion is used to operate the piston of an air pump through linkage.

The pump may be anchored or moored to the sea bed.



Several float operated air pumps are used to store energy in a compressed air storage.

The compressed air is used to generate electricity through an air turbine coupled to a generator.




*Heaving float systems*

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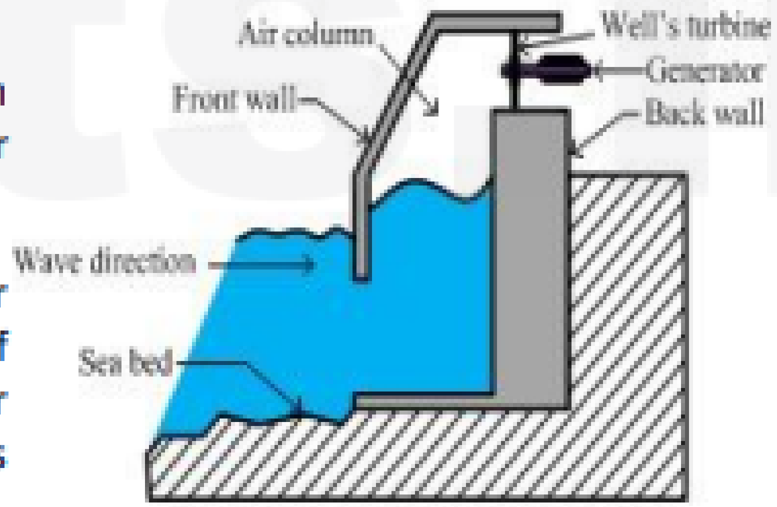
# Oscillating water column device

It comprises of a partly submerged concrete or steel structure which has an opening to the sea below the water line, thereby enclosing a column of air above a column of water.

The column fills with water as the wave rises and empties as it descends. In the process, air inside the column is alternately compresses and de-pressurizes the air column. The air is then allowed to flow through a turbine, which drives the generator.

The axial flow Wells turbine, invented in the 1970's, is the best known turbine for this kind of application.

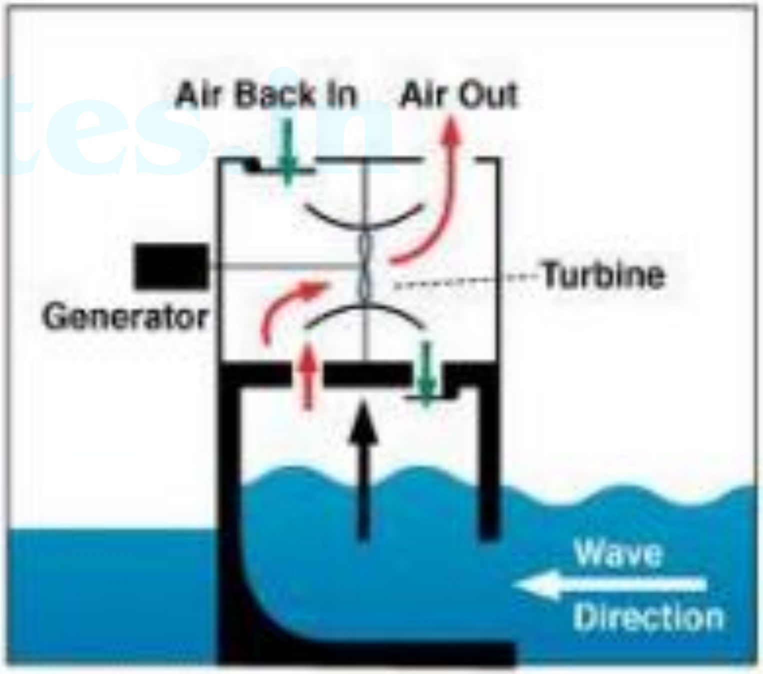
A 150 kW prototype OWC with harbor walls was built onto the breakwater of the Vizhinjam Fisheries harbour, near Thiruvananthapuram in India. But this project is not operational at present.




*Oscillating water column device (OWC)*

# Principle of OWC Wave Energy

- The kinetic energy of moving waves can be used to power a turbine.
- In this simple example the wave rises into a chamber. The rising water forces the air out of the chamber. The moving air spins a turbine which can turn a generator.




- When the wave drops, this creates a vacuum in the chamber, causing air to flow in the opposite direction

# Oscillating Water Column

An Oscillating Water Column (OWC) consists of a partially submerged structure that opens to the ocean below the water surface. This structure is called a wave collector.

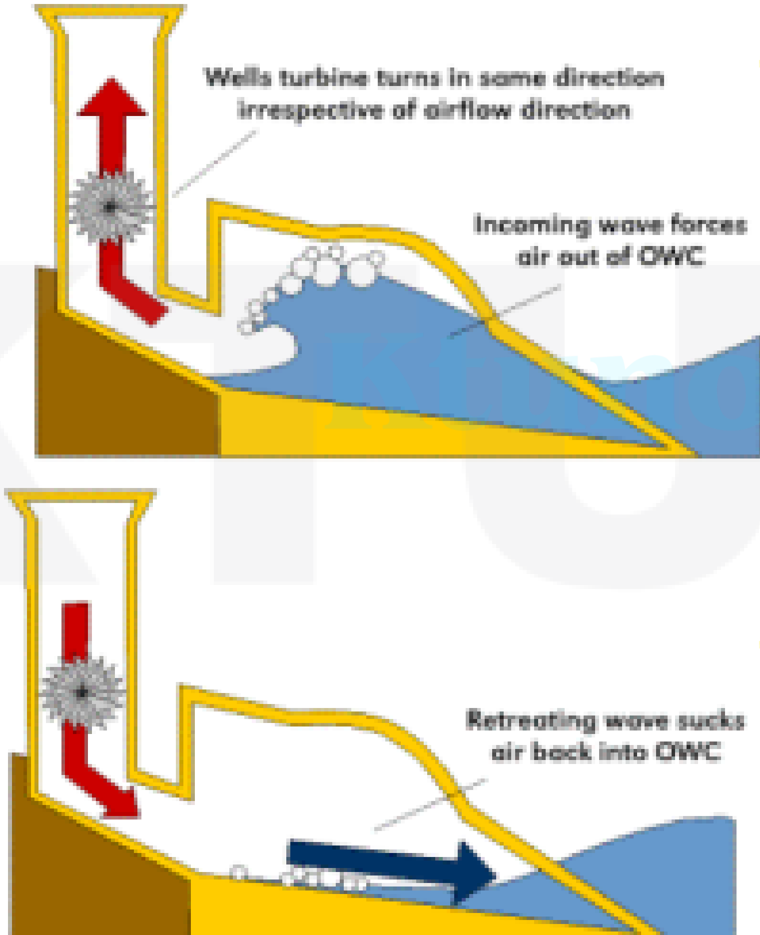
This design creates a water column in the central chamber of the collector, with a volume of air trapped above it.

The type of turbine used is a key element to the conversion efficiency of an OWC.

Traditional turbines function by gas or liquid flowing in one direction and at a constant velocity.

When the flow is not always from the same direction or at a constant velocity – such as in the OWC – traditional turbines become ineffective.

# Oscillating Water Column




- As a wave enters the collector, the surface of the water column rises and compresses the volume of air above it.
- The compressed air is forced into an aperture at the top of the chamber, moving past a turbine.
- As the wave retreats, the air is drawn back through the turbine due to the reduced pressure in the chamber.

# Thank you