CHAPTER

8 Ocean Energy

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8.1. INTRODUCTION

The *oceans, large lakes and bays are huge reservoirs* of various useful and *renewable energy sources.* World's total estimated ocean energy reserves are about 130×10^6 MW. However, only a *fraction* can be recovered *economically.*

Due to rapidly depleting fossil fuel sources, the *ocean energy* is likely to gain a significant importance during coming decades. However, its present use is very limited.

Oceans receive water from the rivers in various parts on the earth. Ocean is a great collection of salt water that covers approximately 70 percent of earth's surface. Five principal oceans are:

1. Indian ocean;
2. Pacific ocean;
3. Atlantic ocean;
4. Arctic ocean;
5. Antarctic ocean.

Oceanography *is the science which deals with the environment in the oceans including the waters, depths, beds, biomass, energy resources etc.*

The various ocean energy technologies are presently in infant stage and their commercialisation is likely to take several more decades.

8.2. OCEAN ENERGY SOURCES

Ocean energy sources may be broadly divided into the following *four* categories:

1. *Tidal energy.*
2. *Wave energy.*
3. *Ocean thermal energy conversion (OTEC).* This concept was proposed as early as 1881 by the French physicist Jacques d'Arsonal.

4. *Hydroelectric energy*—Energy emanated from the *sun-ocean system* from the mechanism of surface water evaporation by solar heating *i.e. hydrological cycle".* 1. **Ocean tidal energy.** It refers to the *hydroenergy in ocean tides*. Ocean tides occur *due to gravitational attractive forces from sun and moon.* The level of the ocean water rises periodically during high tides and drops during low tides. The difference in head of water during high tide and low tide is used for rotating hydro turbine generator units installed within barrages (dams) to obtain electrical energy. 2. **Ocean wave energy.** It refers to the *waves of water from ocean to the shore.* Ocean waves occur *due to rotation of earth and the winds over ocean surface.* Waves have an interval of 4 to 12 seconds and crest of a few centimetres to about 10 m. Locations having waves with crest height of *3 m and above have higher energy density*. Ocean *wave machines* are installed on *floating power plants* or *on-shore power plants.* The rotor of the wave machine is rotated by wave energy. Wave machine drives generator rotor or pumps water to the reservoir at higher level.

3. **Ocean thermal energy.** It refers to the *thermal energy acquired by the ocean water from solar radiation.* The warm water from upper levels of ocean (at about 25°C) is pumped through *heat exchangers.* Thermal energy is extracted and converted to electrical energy by steam turbine-generator or vapour turbine-generator. Cold water from the bottom of the sea (at about 10°C) is used for condenser.

    - **Ocean current energy.** *Energy from ocean currents* refers to *hydro-energy in water currents through the large rivers terminating in the ocean.* The currents have kinetic energy which is converted into electrical energy by turbine generators.

    • *Ocean wind energy* refers to off-shore wind energy resources over oceans. • *Ocean biomass energy* refers to organic matter from oceans e.g. aquatic vegetation, algae and animals. Rapidly growing varieties of ocean algae, ocean kelp are harvested periodically. The ocean biomass may be converted into *methane rich biogas* by *wet anaerobic digestion process.* Alternatively, biomass may be *dried* and *burnt*.

- *Ocean nuclear energy* resources refer to nuclear energy resources obtainable from ocean water or ocean beds.

4. **Hydroelectric energy.** The hydrogical cycle results in rainfall, which causes river flows that can be trapped behind *dam to even out the variations in the river flows* and thus become source of either *low-head or high-head (dam) hydroelectric energy. Small scale hydroelectric facilities* can supply in principle significant amounts of electricity for irrigation or portable water pumping, lighting, health and educational purposes. The total amount of such a resource is very poorly documented but apt to be large.

8.3. TIDAL ENERGY

8.3.1. Introduction

*The periodic rise and fall of the water level of sea which are carried by the action of the sun and moon on water of the earth is called the **'tide'**.*

The daily variation in tidal level is mainly due to the *changing position of the moon.* • Tidal energy can furnish a significant portion of all such energies which are renewable in nature. The large scale up and down movement of sea water represents an *unlimited source of energy.* If some part of this vast energy can be converted into electrical energy, it would be an important source of hydropower. • The *main feature of the tidal cycle is the difference in water surface elevations at the high tide and at the low tide.* If this differential head could be utilized in operating a hydraulic turbine, the tidal energy could be converted into electrical energy by means of an attached generator.

8.3.2. Tidal Range (R)

The tidal range is the difference between consecutive high tide and low tide water level. It is denoted by *R* and is measured in metres.

***Tidal energy** refers to the potential energy in the tidal range.*

Fig. 8.1. Tidal range [Daily (diurnal) tides].

Fig. 8.1 shows the *time versus water-level characteristics* of ocean tide for a *lunar day.* The tidal curve against time is approximately sinusoidal. Range (*R*) is the difference in water level of high-tide crest and low-tide crest. This difference is utilised to obtain the head of water between ocean-side and basin-side of the barrage (dam). • *Tidal range (amplitude)* varies widely depending upon *geographical location*, *contour of ocean bed, depth of oceans, distance from coasts etc.* It is *insignificant in the middle of ocean* and *significant near coast.* Tidal ranges of 0.25 m to 17 m have been recorded in different locations.

Tidal range is not constant at the same collection but *varies* with lunar days in the month. A lunar month is of 29.5 days.

8.3.3. Production of Ocean-tides

Fig. 8.2 explains how ocean-tides are produced.

— **Spring tides** *are those in which the tidal range is maximum on full moon and new moon.*

Last quarter
High tide
Hig h t i d e
Low tide
New
Low tide
Low tide
Sun
g i h
tide Neap
Full
moon
H
Earth
Low tide
moon
Spring tides
tides
Earth
High tide
First quarter

Fig. 8.2. Production of ocean-tides.

— *The tides in which the tidal range is minimum* on first quarter and third quarter are called **Neaptides.**

Fig. 8.3 shows a record of daily and monthly tides in a complete lunar month.

Fig. 8.3. Record of daily and monthly tides.

- **Daily cycle** is due to *rotation of earth about its axis producing two crests and two ebbs in one lunar day* (Fig. 8.1)
- **Monthly cycle** is of *two maximas and two minimas in one lunar month of 29.5 days.* This cycle is *due to changing position of the moon and sun with one revolution of the moon around the earth.*

The tidal range has a typical *daily variation* superimposed on a *monthly variation.*

8.3.4. Origin of Tides (Tidal Phenomenon)

The tidal energy *is due to the gravitational force of attraction between the earth and sun and between earth and moon.*

The gravitational force F between two bodies, say between sun and a molecule on earth, is given by:

$$F = \frac{KMm}{d^2} \quad \text{...(8.1)}$$

where, M = Mass of sun,

m = Mass of water molecule,

d = Distance between sun and water molecule, and K = Gravitational constant.

The gravitational force between moon and a water molecule will also be given by a similar equation. Since distance between moon and earth is lesser than that between sun and earth, the attraction between moon and water molecule is about 2 to 3 times that between sun and molecule.

- The moon revolves around the earth with a period of 24 hours 50 minutes per one revolution. The earth's surface facing the moon experiences greater attractive force than the surface away from the moon. Thus ocean water on the moon side experiences a swell (hide tide) and the other side experiences low tide. Such daily tides are called the *diurnal tides* (Fig. 8.3)
- The relative positions of the sun, the moon and the earth have hourly variation, daily variation. Hence tides are affected by these relative positions. *Spring tides* and *Neap tides* are caused by relative positions of the moon and the sun with respect to the position of ocean on the earth surface (Fig. 8.3).

8.3.5. Estimation of Energy Potential For a Tidal Power Project

To utilise tidal energy, water must be trapped at high side behind a dam or barrage and then made to drive turbine as it returns to sea during low side. The *available energy is proportional to the square of the amplitude of tide.* As such the available energy tends to be concentrated around regions of high side. *The amount of generation depends only on the tidal phenomenon and can be predicted fairly accurately.*

Because of the *variations in tidal pattern, the power output shows some variations as under:*

1. *Two bursts of generation activity per day,* beginning about 3 hours before high tide and lasting from 4 to 6 hours.
2. The power output in each tidal cycle will *increase* with the difference between high and low tides. Thus the power output curve will *display a 14 day cycle.* 3. The high tide time *shifts by about one hour every day* and the *power output will show a similar shift.*
4. Spring tide high water always occurs at the same time. Thus the maximum availability will *not be disturbed evenly during the day*.

Tidal power schemes are of two types:

1. Single basin scheme.
2. Two basin scheme.

8.3.5.1. Energy and power in a single-basin single-effect/cycle scheme A single basin scheme is *cheaper.* However it is not very useful due to the above mentioned reasons in power output. This scheme produces power output, which *follows phases of sun and moon and not the load demand of the system.* Therefore, a single basin tidal power scheme would always *need a standby plant.*

Fig. 8.4 shows a single-basin single-effect tidal power scheme. It is the case of basin *beginning at high-tide level*, **emptying** *through the turbine to ocean, which is at 'low tide'*; head (h) varying from (+R) to 0.

In case of a *'Double cycle system'*, power is generated while *"filling"* the basin and *also while "emptying"* the basin. Hence double cycle scheme gives *"double energy"* per tide cycle of one crest and one ebb.

Fig. 8.4. Single-basin single-effect tidal system–"Emptying only".

Let, A = Area of basin, considered constant, m^2, ρ = Density of water, kg/m^3,

g = Gravitational constant,

m = Mass flowing through the turbine, kg, h = Head, m, and

W = Work done by water flowing through turbine, J. For tidal range (amplitude) R, and certain head (h) at the given time during the flow from the ocean to basin, the *differential work done (dW)* is equal to the *change in potential energy* due to change in mass (dm) of water. Hence,

$dW = dm.g.h$, J

But, $dm = -\rho.A.dh$

(–ve sign indicates *decrease* in the mass of water during in *emptying operation*)

So, that $dW = -\rho.A.dh.g.h$, J

The *total work done* (W) by water while *emptying* the basin is obtained by integrating dW from R to 0,

$$W_{emp.} = \int_R^0 dW = \int_R^0 -\rho.A\,dh\,g\,h = -\rho g A \int_R^0 h\,dh$$

$$= -\rho g A \left[\frac{h^2}{2}\right]_R^0 = \frac{1}{2}\rho g A R^2$$

i.e., $W_{emp.}$ (or Energy) $= \frac{1}{2} g\rho A R^2$, J ...(8.2) where, ρ = Sea density in $kg/m^3 = 1025\ kg/m^3$; $g = 9.81\ m/s^2$ Eqn. (8.2) indicates that *work is proportional at to square of the tidal range.* ● The **power** *is the rate of doing work.*

The power is generated during emptying (or filling) and no power is generated during rest of the time.

The average power (theoretical) delivered $= \dfrac{W}{\text{time}}$

The duration of time for single effect is 6h 12.5 min which is equal to 22,350 seconds.

$$\therefore P_{av.} = \frac{W}{\text{time (s)}} = \frac{\frac{1}{2}\rho g A R^2}{22,350} = \frac{9.81 \times 1025}{2 \times 22,350}\, AR^2 = \frac{9.81 \times 1025}{44,700}\, AR^2$$

i.e., $P_{av} = 0.225\, AR^2$ ...(8.3) and

$$\frac{P_{av.}}{A} = 0.225\, R^2\ \text{W/m}^2 = 0.225\, R^2\ (\text{MW/km}^2) \quad \text{...[8.3 (a)]}$$

The average power generated is calculated based on average operating head of $\frac{R}{2}$ which is available only for limited period under a single-basin emptying operation. There are friction losses, conversion efficiencies of the turbine and generator that *reduce the power.* Studies have shown that the optimal annual energy production is *about 30 percent* of the average theoretical power.

Example 8.1. *A tidal power plant of single-basin type, has a basin area of 24 km^2. The tide has a range of 10 m. The turbine stops operation when the head on it falls below 3m. Calculate the average power generated during one filling/emptying process in MW if the turbine-generator efficiency is 75 percent. Density of sea water = 1025 kg/m^3; g = 9.8 m/s^2.*

Solution. *Given:* $A = 24$ km^2 $= 24 \times 10^6$ m^2; $R = 10$ m; $r = 3$ m (the heat before turbine stops operating); $\eta = 0.75$; $\rho = 1025$ kg/m^3; $g = 9.81$ m/s^2.

Average power generated, P_{av}:

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

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

Thus, average power generated,

$$P_{av.} = \frac{W}{\text{Time}} = \frac{\rho g A (R^2 - r^2)}{2 \times 22350} \quad \text{.... (2)}$$

$$= \frac{1}{44,700} \times 9.81 \times 1025 \times (24 \times 10^6)(10^2 - 3^2) \times 10^{-6}\ \text{MW}$$

or, $P_{av.} = 491.3$ MW

$\therefore$ Power generated $= 491.3 \times 0.75 =$ **368.5 MW (Ans.)**

8.3.5.2. Energy and power in a single-basin double-effect/cycle scheme

Fig. 6.5 shows a single-basin double-effect/cycle tidal power system. In this system energy is converted into electrical energy during flood tide *(rising tide)* when the basin is *filled* and *also* during the ebb tide *(falling tide)* when the basin is *emptied*. Since water flows through the turbine during rising and falling tides in *apposite directions,* therefore, a **reversible turbine** is used, which acts as a turbine for either direction of flow.

The average theoretical power from a double-cycle/effect scheme is **twice** that of a similar single-effect scheme. Thus, the theoretical average power generated (using eqn. 8.3),

$$(P_{av.})_{\text{double-effect}} = 2 \times 0.225\, AR^2 = 0.45\, AR^2 \quad \text{...(8.4)}$$

Dam or dyke

High tide

Low tide

Tidal basin

Sea

Tidal basin

Turbine generator set (Reversible turbine)

(b) Falling (Low) tide

(a) Rising (High) tide

Fig. 8.5. Single-basin double-effect/cycle system.

This system is 100 percent more efficient that single-effect system/plant because it generates *double* energy per cycle.

8.3.6. Power Generation (Yearly) From Tidal Plants

The energy available from a tidal plant depends on the following *two* factors:

(*i*) The tidal range.

(*ii*) The volume of water accumulated in the basin.

Tidal energy is slowly-increasing hydro-energy during filling of the basin, and after a period of nearly 3 hours it attains its *peak value*. When the tide *recedes,* water is allowed to flow from basin to sea; it is then *slowly-decreasing hydro-energy* and attains its *lowest value* when the turbine stops after a period of 3 hours. Thus, the energy available for a tidal point can be calculated in a similar way as for an hydropower plant; *i.e.*, *considering the average discharge and available head at any instant*.

Let, A = Average cross-sectional area of the basin, m^3 H = Difference between maximum and minimum water levels, m, and

V = Volume of basin, m^3.

Now, $V = AH$

$\therefore$ Average discharge, $Q = \frac{AH}{t}$

where t is the total duration of generation in one filling/emptying operation in seconds.

Now, power generated at any *instant*,

$$P_{\text{inst.}} = \frac{\rho Q h}{75} \cdot \eta \text{ H.P.} \quad \text{...(8.5 a)}$$

$$\text{or, } P_{\text{inst.}} = \frac{\rho Q h}{75} \cdot \eta \cdot 0.736 \text{ kW} \quad \text{...(8.5 b)}$$

where, h = available heat at that instant, m,

ρ = 1025 kg/m^3 for sea water,

η_0 = Overall efficiency of the system, and 1 H.P. = 75 kgm/s.

$$\text{Then, total energy} = \int_0^t P\,dt = \int_0^t \frac{\rho Q h}{75} \cdot \eta_0 \cdot 0.736 \text{ kW}\, dt \text{ per tideal cycle} \quad ...(8.6)$$

On average, there are *705 tidal cycle in a year*. Then,

yearly power generation from a tidal project

$$P_{yearly} = \int_0^t \frac{\rho Q h}{75}\, dt \times \eta_0 \times 0.736 \times 705 \text{ kWh/year} \quad ...(8.7)$$

Example 8.2. *For a proposed tidal site, the observed difference between high and low water tide is 9 m. The basin area is about 0.45 sq. km which can generate power for 3 hours in each cycle. The average available head is assumed to be 8.5 m, and overall efficiency of the generation is 72 percent. Assume density of sea water as 1025 kg/m^3. Calculate:*

(*i*) *Power at any instant.*

(*ii*) *Yearly power output.*

Solution. *Given*: H = 9 m; A = 0.45 × 10^6 m^2; t = 3 hours; h = 8.5 m; η_0 = 72%, ρ = 1025 kg/m^3.

Volume of basin = AH

= 0.45 × 10^6 × 9 = 4.05 × 10^6 m^3

$$\therefore \text{Average discharge, } Q = \frac{\text{Volume}}{\text{Time period}} = \frac{4.05 \times 10^6}{3 \times 3600} = 375 \text{ m}^3/\text{s}$$

(*i*) **Power at any instant ($P_{inst.}$):**

$$P_{inst.} = \frac{\rho Q h}{75} \cdot \eta_0 \cdot 0.736 \text{ kW} \quad ...[\text{Eqn. (8.5b)}]$$

$$\text{or, } P_{inst.} = \frac{1025 \times 365 \times 8.5}{75} \times 0.72 \times 0.736 = \mathbf{23085\ kW\ (Ans.)}$$

(*ii*) **Yearly power output:**

Energy generated per tidal cycle

= 23085 × 3 = 69,255 kWh

Total number of tidal cycle in a year = 705

$\therefore$Year power output, P_{yearly} = 69,255 × 705 = **488.25 × 10^5 kWh/year (Ans.)**

8.3.7. Site Requirements for a Tidal Power Scheme

A favourable *site* for tide power scheme should meet with the following *requirements*:

1. The site should have a *large tidal range.*
2. Capable of *storing a large quantity of water* for energy production with minimum dam and dyke construction.
3. To achieve a high storage capacity, the site should be located in an *estuary or a creek.*
4. It should be near to a load centre to minimise the transmission requirements. • The following *points* need to be considered prior to the development of a tidal power scheme:

1. **Pre-feasibility study.** It pertains to the collection of data such as tides, local topography, infrastructure, etc. During this study following should be collected: (*i*) Local land area map, survey of India map and hydrographic charts, (*ii*) Historical data on tides and tidal currents; (*iii*) Geotechnical properties of sea bed and coastal region in the study area; (*iv*) Typical weather conditions, rainfall, wind and wave data; (*v*) Nearest high voltage substation for connecting the generated electric power with the state grid.
2. **Feasibility study.** This phase of the development of tidal power scheme consists of the following:

— Mathematic modelling;

— Preliminary energy computation;

— Foundation investigations;

— Hydraulic model studies;

— Detailed analysis of various modes of operation.

3. Detailed design.
4. Preparation of specifications and tender documents.
5. Plant construction.

8.3.8. Components of a Tidal Power Plant

A tidal power plant consists of the following *three components:*

1. Dam or dyke (low wall);
2. Sluice ways;
3. Power house.

1. **Dam or dyke (barrage).** The function of dam or dyke is to form a barrier between the sea and the basin or between one basin and the other in case of multiple basin schemes.

— It should be constructed by the material available at site or from a nearby place.

— As the barrage has to withstand the force of sea waves, so the design should be suitable to the site conditions and to economic aspect of development. — The crest and slopes of the barrage should be armoured for protection against waves.

2. **Sluice ways.** These are used to *fill* the basin during the *high tide* or *'empty'* the basin during the low tide, as per operational requirement. These devices are controlled through gates.

There are two types of sluice ways:

(*i*) *Crest gates*: These are more prone to damage by wave action and masses carried by the flow.

(*ii*) *Submerged gates with venturi type*: Vertical gates are the natural choice and can be fabricated from stainless steel.

3. Power house. A power house has *turbines, electric generators* and other auxiliary equipment. As far as possible, the power house and sluice ways should be in *alignment* with the dam or dyke.

According to the suitability, for low heads the following turbines may be used; (*i*) Bulb turbine; (*ii*) Tube turbine, and (*iii*) Straight flow rim type turbine.

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8.3.9. Types of Tidal Power Plants

Sluice
Ocean

Tidal power plants are *classified* as follows:

1. *Single-basin arrangement*:

(*i*) Single-effect plant.

(*ii*) Double-effect plant.

2. *Double-basin arrangement:*

(*i*) Double-basin, paired-basin plant. (*ii*) Double-basin, linked-basin plant.

8.3.10. Single-Basin Tidal Plants

Fig. 8.6 shows the layout of a single-basin tidal plant.

Barrage

Turbines

Power plant

Basin
ways

Barrage

Fig. 8.6. Layout of a single-basin tidal plant.

— A barrage (Dyke, dam) separate, the basin from the sea.

— The sluice way is opened during high tide to fill the basin.

— The turbine-generator units are mounted within the ducts inside the barrage.

— Power house is built on the barrage.

- A single-basin tidal plant *cannot generate power continuously.*
- In these plants, *pumped storage capacity* may be incorporated to fill water to a higher level and empty the basin to lower level. A pumped storage plant is useful *when the load it supplies fluctuates considerably.*

8.3.10.1. Single-basin single-effect plant

Refer to Fig. 8.4. Such a plant generates power only with *one-way* flow of water through the turbines, *i.e.*, during low tide.

— The *basin is filled during the 'high-tide'* by opening the gates in the barrage. The water level in the basin reaches the crest level of the tide. The energy is stored in the form of tidal range. Tidal range gives the *head of water during the 'low tide;.*

— Initially, during the *low tide,* the level in the basin is *R* is *zero.* Water is released during the *generating mode* through the turbines, spillways located within the barrage, into the sea.

— The turbines are started only when the head reaches (*R*) *i.e.*, water in the basin is at high tide level and water in the sea is at low tide level. The turbines are designed for *single way operation. Only fixed blade turbines are necessary.*

Power generation is *intermittent* and mostly during off-peak load periods on daily load curves.

Fig. 8.7. indicates the flow intervals in a simple single-basin and single-effect plant.

Fig. 8.7. Time and operating modes of simple single-basin single-effect tidal power plant. 1. *First waiting mode*:

— It begins with the falling water level and lasts for 1.5 hours (approx.) to allow the ocean water level to reduce and head H to increase.

— The basin level remains at top during the waiting mode.

2. *Generating mode*:

— This mode begins, when the ocean level reduces to required mark and the head H reaches required value.

Head = Basin water level-sea water level

— The turbine-gates are opened, and the pool water flows through the turbines (during this mode).

— This mode continues during 'emptying' of the basin and last for 4.5 hours (approx.)

3. *Second waiting mode*: The generating mode is followed by another waiting mode, during the rising tide.

4. *Refilling mode*: Its duration is 4.0 hours (approx.) during the rising tide.

8.3.10.2. Single-basin double-effect plant

Refer to Figs. 8.5 and 8.8. This is a *two-way scheme, Ebb and flood operation.* ***Reversible turbines*** are installed and *power is generated during 'filling' and 'emptying' of the basin*. — The basin *fills* in during *rising tide (flooding)*. The water flows from the sea to the basin and drives the reversible turbines.

— The basin is *emptied* during *lowering-tide (ebbing).*

Water flows from the basin into the sea and drives the reversible turbines.

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Fig. 8.8. Single-basin double-effect tidal plant, sluicing and turbining flow directions. Fig. 8.9 shows the *operating modes* of single-basin double-effect tidal power plant.

Fig. 8.9. Operating modes of single-basin double-effect tidal power plant

(Fig. 8.5). The operating modes during 12 h 25 min half-tidal cycle are:

1. *Generating mode* during *emptying.*

2. *Sluicing*—letting out water through sluice during low net heads. 3. *Generating period* during *filling*—sluices are closed, water is let out from the basin through the turbines.

4. *Second sluicing period.*

Energy conversion in half tidal period of 12h 25 min is *twice* that of a single-basin single-effect plant.

In a *single-basin, double-effect, 'pump turbine plant' in addition,* the turbines are used as pumps to increase or reduce the water level of the basin/reservoir some energy is spent to drive the pumps.

- Although the double-cycle system has *only short duration interruptions in turbine operation,* yet a *continuous generation of power is still not possible.* Furthermore the *periods of power generation coincide only occasionally with periods of peak demand.* These problems are overcome to some extent in the double-basin scheme.

8.3.11. Double-Basin Tidal Plants

A *'double-basin scheme' can produce continuous power output.* The *drawback* is that the civil works become *more extensive.*

Several tidal energy conversion projects under planning are of *double-basin type.* These plants may be of the following *two types*:

1. Double-basin, linked-basin plant.
2. Double-basin, paired-basin plant.

8.3.11.1. Double-basin, linked-basin scheme

Refer to Fig. 8.10. In this scheme a single larger basin is divided into two basins called *high basin* and *low basin.* These basins are separated by means of a *partition barrage.* The *main barrage* is built between the sea and the two basins.

— *High basin* gets periodically *filled* during every *high tide* from ocean water through sluice S_h.

— *Low basin* gets periodically *emptied* by flow to ocean through sluice S_l during *low tide*.

Fig. 8.10. Double-basin, linked-basin scheme.

— Turbine-generator set(s) are installed in the partition barrage. Water flows from high basin to low basin is through turbines. This flow is controlled such that *continuous power* is obtained from the plant, without waiting for tidal sequence. *High basin acts as an energy reservoir.*

— The capacities of the two basins should be *large enough* in relation to the water flow through the turbines so that *fluctuations in head of water* (the difference in levels between high basin and low basin) during power generation is *minimised.*

8.3.11.2. Double-basin, paired-basin scheme

Refer to Fig. 8.11. In a double-basin, paired-basin scheme *two barrages are built between the ocean and each basin.* In such a scheme, supplementary pair-basins, can be added and the total scheme becomes a *'multiple basin scheme'* with a few paired basins.

Fig. 8.11. shows a schematic diagram of a double-basin, paired-basin scheme. In this scheme, *power is generated during low tide and high tide.*

— During high tide, high basin is *filled* by *sluice* S_h.

— During low tide, high basin *discharges* via *turbine* (*s*).

— During high tide, low basin is *filled* via *turbine* (*s*).

— During low tide, low basin is *sluiced via* S_l.

Fig. 8.11. Double-basin paired-basin scheme.

Limitations:

1. Although this scheme leads to continuous output, yet its power supply remains irregular and there is *no solution for equalising the great difference in output between the spring and the neap tide operation.*
2. It is *difficult to find two tidal sites within reasonable distance of each other having the requisite difference is time of high water.*

8.3.12. Advantages and Disadvantages of Tidal Power

Following are the *advantages and disadvantages of tidal power*:

Advantages:

1. Tidal power is completely *independent of the precipitation (rain) and its uncertainty.*
2. *Large area* of valuable land is *not* required.
3. It is *inexhaustible* and a *renewable source of energy.*
4. It is *free from pollution.*
5. When a tidal power plant works in combination with thermal or hydroelectric system, *peak demand can be effectively met with.*
6. The *net-cost of power generated is quite low.*

Disadvantages/Limitations:

1. Due to variation in tidal range the output is *not uniform.*
2. Since the turbines have to work on a wide range of head variation (due to variable tidal range) the *plant efficiency is affected.*
3. There is a fear of *machinery being corroded* due to corrosive sea water. 4. It is *difficult* to carry out *construction in sea.*
5. As compared to other sources of energy, the tidal power plant is *costly.* 6. *Sedimentation and silteration of basins* are the problems associated with tidal power plants.
7. The *power transmission cost is high* because the tidal power plants are located away from load centres.

8.3.13. Global Scenario of Tidal Energy

The details of tidal power plants in the world's are given in the table 8.1 below:

Table 8.1: Tidal power plants in the world.

S.No.	Location	Year	Total capacity	No. of units	Tidal range (*m*)
1.	*France:* La Rance Brittany	1966	240 MW	24	8.5
2.	*Russia:* Kislaya Guba	1968	400 kW	1	3
3.	*Canada:* Annapolis NOVA Scotia	1974	17.8 MW	1	5.5
4.	*China:* (*i*) BAISHAKOU (*ii*) JIANGXIA	1978 1980	960 kW 3.0 MW	6 × 160 kW 6 × 500 kW	3.5 to 7.8 5

In *India,* following are the major sites where preliminary investigations had been carried out:

(*i*) Bhavanagar;
(*ii*) Navalakh (Kutch);

(*iii*) Diamond harbour;

(*iv*) Ganga Sagar.

The *basin in Kandla in Gujrat has been estimated to have a capacity of 600 MW.* The *total potential of Indian coast is around 9000 MW,* which does not compare favourably with the sites in the American continent states. The technical and economic difficulties still prevail.

8.3.14. Economic Aspects of Tidal Energy Conversion

The cost of a tidal energy conversion scheme includes: (*i*) Cost of barrages, (*ii*) Cost of land of basins and development of basins, and (*iii*) Cost of power plant. The *capital cost per* kWh of energy is therefore *very high.* The running cost and maintenance cost are, however, *low.*

• The mini hydroprojects are more favoured than tidal power plants, • The tidal power plants may be *economically comparable,* in future, when *cost of conventional fuels becomes more prohibitive.*

Inspite of the fact that tidal power plants are costly, they have the following *fringe benefits*:

1. Renewable energy, free of cost for entire period of time.
2. Performance is pollution free.
3. Development of regions on both the sides of the barrage and on the banks of the basin.
4. With pumped storage facility, continuous, dependable large power can be obtained. The rating of tidal power plant is in the range of several tens of MW.
5. Technology of bulb turbines developed for tidal power plants is useful in mini hydro and pumped hydro-power plants.
6. Road on the top of the barrage eliminates the need of a separate bridge.
7. Tourist attraction in tidal power plants and development of tourism.

8.4. WAVE ENERGY

8.4.1. Introduction

Wave energy *comes from the interaction between the winds and surfaces of oceans.* The energy available varies with the *size and frequency of waves.* It is estimated that about *50 kW* of power is available for *every metre width of true wave front.*

Ocean wave energy is due *to the periodic to-and-fro, up-and-down motion of water particles in the form of progressive waves.* The period of ocean waves is the order of a few seconds. Ocean waves are superimposed on ocean water. *Ocean water surface level varies with ocean tidal cycle.*

Ocean waves possess potential energy (P.E.) and kinetic energy (K.E.). The ocean waves originate in different parts of the ocean surface due to the surface winds. The waves travel in the direction of the wind to the shore. The waves may be due to the local winds or the planetary winds. The *height of the waves depends upon the wind velocities, depth of the ocean, contour of the shore etc.*

The typical ranges of ocean waves are:

(*i*) *Wind height* = 2 × amplitude = 0.2 m to 4 m

(*ii*) *Wave period* = 4 s to 12 s.

Very dangerous and destructive waves occur during storms and gusts. They may reach heights of 10 *m* and may topple ships and damage the ocean energy plants.

- Wave energy when active is very concentrated, therefore, wave energy conversion into useful energy can be carried out at *high power densities.* A large variety of devices (*e.g. hydraulic accumulator wave machine; high-level reservoir machine; Dolphin-type wave-power machine; Dam-Atoll wave machine)* have been developed for harnessing of energy but these are *complicated and fragile in face of gigantic power of ocean storms*.

8.4.2. Advantages and Disadvantages

Following are the *advantages* and *disadvantages* of wave energy:

Advantages:

1. It is relatively pollution free.
2. It is a free and renewable energy source.
3. After removal of power, the waves are in placed state.
4. Wave-power devices do not require large land masses.
5. Whenever there is a large wave activity, a string of devices have to be used. The system not *only produces electricity but also protects coast lines from the destructive action of large waves, minimises erosion and help create artificial harbour.* **Disadvantages:**

1. Lack of dependability.
2. Relative scarcity of accessible sites of large wave activity.
3. The construction of conversion devices is relatively complicated. 4. The devices have to withstand enormous power of stormy seas. 5. There are unfavourable economic factors such as large capital investment and costs of repair, replacement and maintenance.

Problems associated with wave energy collection:

The collection of wave energy entails the following *problems:*

1. The variation of frequency and amplitude makes it an unsteady source. 2. Devices, installed to collect and to transfer wave energy from far off oceans, will have to withstand adverse weather conditions.

- Until now no major development programme for taming wave energy has been carried but successfully by any country. Small devices are available, however, and are in limited use as power supplies for buoys and navigational aids. From the engineering development point of view, wave energy development is not nearly as far long as wind and tidal energy.

8.4.3. Factors Affecting Wave Energy

Wave energy is affected by the following *three major factors:*

1. **Wind speed.** With the increase in wind speed, there is an increase in wind energy.
   — The amplitude of the waves depends on wind speed.
   — During storms and gusts, big ocean waves occur, which prove highly detrimental even to ships.
2. **Effective pitch value.** It is the *uninterrupted distance* on the ocean over which the wind can below before reaching the point of reference. The *larger* the distance, the *higher* the wave energy. This distance may vary from 5 km to 45 km.
3. **Depth of ocean water.** The greater the depth of ocean water the higher the wave velocity. Very large energy fluxes are available in deep ocean waves.

8.4.4. Parameters of Ocean Waves

A **progressive wave** *(travelling wave) is a wave whose crest line moves in the direction of propagation of wave.*

The important parameters and their notations are:

Fig. 8.12: Parameters of a progressive ocean wave

λ = Wavelength (= $C \times T$, where C is the phase velocity and T is the period), *m;*

α = Amplitude = $\frac{H}{2}$ (where H is the wave height), *m;*

B = Width along crest line, *m;*

A = Area of wave = $\lambda \times$ B, m^2 (see Fig. 13); f = Frequency, number of periods per second $= \frac{1}{T}$.

Wave velocity

Crest line

B (width of water wave)

Trough line

Area A = λxB λ

Fig. 8.13: Water wave length λ and width B.

The relation between λ and T is given by:

$\lambda = 1.56\ T^2$ metre

- The energy available in random sea is expressed as:

$\rho = 0.96\ H^2T$ kW/*m* of wave crust ...(8.8) where, H = The wave heigh, *m* and T = The wave period, *s.*

Waves in ocean are not regular sine waves but random in nature.

8.4.5. Energy and Power from Waves

Fig. 8.14 shows a two-dimensional progressive wave, represented by the sinusoidal simple harmonic wave shown at time, τ = 0, and at time τ. Although the sea waves are highly irregular yet, such a wave is assumed to be of sinusoidal harmonic wave shape for the purpose of mathematical analysis. The wave is moving in the direction of *x*–axis.

Fig. 8.14: A typical progressive wave, at time $\tau = 0$ and time τ.

Consider a point *L* (*x*, *y*) on the wave surface with an element of thickness *dx* along the *x*-axis with a coordinate *y* on the *y*-axis. This sine wave may be expressed by the following relation:

$$y = a \sin\left(\frac{2\pi x}{\lambda} - \frac{2\pi\tau}{T}\right) \quad \text{...(8.9)}$$

where, y = Height above mean level, *m*,

a = Amplitude, *m*,

λ = Wave length, *m*,

τ = Time, *s*, and

T = Period, *s*.

Let, $m = \frac{2\pi}{\lambda}$, and $n = \frac{2\pi}{T}$

Then, eqn. (8.9) reduces to:

$$y = a \sin (mx - n\tau) \quad \text{...(8.10)}$$

where, $(mx - n\tau) = 2\pi\left(\frac{x}{\lambda} - \frac{\tau}{T}\right)$ = Phase angle, dimensionless.

Potential energy (*PE*):

The potential energy depends on the elevation of water above mean level (*i.e.*, $y = 0$). In order to calculate the potential energy of elevated water, let us find out the work to be done in raising the quantity of water to the elevated height as given below: Work done = Force × distance = *mgh* joules

where, m = Mass of water element dx

$= \rho \times y\,dx \times B$, kg

$h = \frac{y}{2}$ (i.e., mean height), m,

ρ = Density of sea water, kg/m^3, and

B = Wave width

$\therefore$ Work done $= \rho \times (y\,dx \times B) \times g \times \frac{y}{2}$

or, Potential energy $(PE) = \frac{1}{2} g\rho y^2 B\,dx$ ...(8.11)

Inserting the value of y from Eqn (8.10) in Eqn. (8.11) and integrating from 0 to λ for wave area X × B, we get:

$$PE = \frac{1}{2} g\rho B \int_0^{\lambda} a^2 \sin^2 (mx - n\tau)\,dx, \text{ assuming } \tau = 0$$

$$= \frac{1}{2} g\rho B a^2 \left[\frac{x}{2} - \frac{\sin 2mx}{4m} \right]_0^{\lambda}$$

i.e., $PE = \frac{1}{4} g\rho B a^2 \lambda$ ...(8.12)

The potential energy gradient per unit area $= \frac{PE}{A}$, where $A = \lambda B$, J/m^2.

$\therefore \frac{PE}{A} = \frac{1}{4} g\rho a^2$ ...(8.13)

Kinetic energy (*KE*):

When the *amplitude a* of the wave is *small compared to its wave length,* then the *PE* and *KE* are *equal.*

$\therefore KE = \frac{1}{4} g\rho B a^2 \lambda$ ...(8.14)

The density of kinetic energy is given by:

$\frac{KE}{A} = \frac{1}{4} g\rho a^2$ ...(8.15)

Total energy (*E*):

$E = PE + KE$ joules

$$i.e., E = \frac{1}{4} g\rho B a^2 \lambda + \frac{1}{4} g\rho B a^2 \lambda = \frac{1}{2} g\rho B a^2 \lambda \quad ....(8.16)$$

Now, Energy density $= \frac{E}{A} = \frac{1}{2} g\rho a^2$ ...(8.17)

($\because$ Area, $A = \lambda B$)

Wave power, *P*:

Power, $P = \frac{\text{Energy supplied}}{\text{Time taken}}$, J/s

= Energy × frequency, watts (W)

$= \frac{1}{2} \rho g B a^2 \lambda f$, watts (W)

Power density $= \frac{P}{A} = \frac{1}{2} \rho g a^2 f$, W/m^2 ...(8.18)

Empirical formulae on wave energy:

1. Scripps formula:

The scripps formula proposed by the Scripps Institution of Oceanography in La Jalla California gives a relationship between wave height and wind velocity as:

$H = 0.085\ U^2$ ...(8.19) where, H = The wave height, m, and

U = The wind speed in knots (1 knot = 1.4 km/h) **2. Zinder Zee formula:**

Zinder Zee formula is given by:

$$H = \frac{KV^2 F \cos a}{D} \quad ...(8.20)$$

where, H = Rise in water level above the normal, m, $K = 6.08 \times 10^{-3}$ (constant),

F = Fetch *i.e.* unobstructed largest dimension of the lake, m, V = Wind speed, km/h,

D = Average water depth, m, and

a = Angle between the wind direction and the fetch. **Example 8.3:** *Ocean waves on an Indian coast had an amplitude of 1.2 m with a period of 6 s measured at the surface water 110 m deep. Taking water density as 1025 kg/m³, calculate the following:*

(*i*) The wavelength,

(*ii*) The wave velocity,

(*iii*) The energy density, and

(*iv*) The power density of the wave.

Solution. *Given*: $a = 1.2$ m; $T = 6\ s$; $\rho = 1025$ kg/m^3

(*i*) Wave length, λ:

$\lambda = 1.56\ T^2$

$= 1.56 \times 6^2 =$ **56.16 m (Ans.)**

(*ii*) Wave velocity, *C*:

We know that, $C = \frac{\lambda}{T} = \frac{56.16}{6} =$ **9.36 m/s (Ans.)**

(*iii*) Energy density:

Energy density $= \frac{E}{A} = \frac{1}{2} \rho g a^2$ ...[Eqn.(8.17)]

$= \frac{1}{2} \times 9.81 \times 1025 \times 1.2^2$

= **7239.8 J/m^2 (Ans.)**

(*iv*) Power density:

Power density, $\frac{P}{A} = \frac{1}{2} g\rho a^2 \times f$ ...[Eqn.(8.18)] $= \frac{1}{2} g\rho a^2 \times \frac{1}{T}$

$\frac{1}{f} = T$

$= \frac{1}{2} \times 9.81 \times 1025 \times 1.2^2 \times \frac{1}{6}$

= **1206.6 W/m^2 (Ans.)**

8.4.6. Characteristics of Waves in Real Oceans

In real oceans, final waves are made up by the combination of component waves; each component wave has different amplitude, wavelength, direction, period, etc. depending upon wind and ocean bed along the routes.

Fig. 8.15: Record of amplitudes of real wave with time.

- The waves generated in deep ocean by distant storms are very high and dangerous, called *swells.* These have *longer wavelengths.*
- The waves in shallow waters and by local winds are *not high* and have *shorter wavelengths*.

8.4.7. Wave Energy Potential

Collection of wave data:

The wave data is collected (by Institutes of Oceanography) by measuring the *parameters* of real ocean waves over a period of 1 to 3 years at selected locations on shore and high oceans.

— The measuring instruments (e.g. accelerometer, integrator, recorder etc.) are mounted on a ship or a buoy. The vertical displacement and vertical acceleration of the ship or the buoy are measured and recorded.

— The *data is scanned* at an internal of every 3 hours over a period of about 20 minutes with duration of 0.5 second per measurement.

— The data is *telemetered to the observatory* on the shore by means of radio communication channels. The data is *recorded* and *analysed.*

From the *analysis of wave data* the following *characteristics are determined:*

1. The significant *height* of the wave.
2. The *period* of significant wave.
3. The energy period.
4. The energy density.
5. The power density.
6. The power per unit width.

From these characteristics of ocean waves, a wave power plant in planned.

- These days the *computer-based methods are used for the analysis of wave data.* Such analysis of wave data helps *to estimate the potential of maximum, minimum and mean power at desired locations.*

Wave energy potential of Indian coast:

India has ample wave energy potential. Some data relating to ocean wave energy, for different locations obtained through measurements, are given in the tables 8.2, 8.3 and 8.4 respectively.

Table 8.2: Wave energy potential on Indian coast

S. No.	*Location*	*North-east monsoon*			*South-west monsoon*		
		Mean wave height (m)	*Mean wave period (s)*	*Wave power (kW/m)*	*Mean wave height (m)*	*Mean wave period (s)*	*Wave power (kW/m)*
1.	Near Calcutta 20-25° N and 85-95° E	1.33	8.00	13.85	1.95	7.65	28.80
2.	Near Vishakapatnam 20-25° N and 85-95° E	1.60	6.25	15.70	2.05	8.25	33.65
3.	Near Chennai 10-15° N and 85° E	1.55	5.85	13.45	1.70	5.80	16.60
4.	Near Cape Camorin 10-15° N and 70° E	1.20	5.35	7.80	1.80	6.30	19.55
5.	Near Mumbai 15-25° N and 70° E	1.00	5.00	4.90	2.65	6.95	47.00

Table 8.3: Wave energy potential near a Tamil Nadu coast

S. No.	*Month*	*Mean wave height (m)*	*Maximum wave height (m)*	*Mean wave period (s)*	*Mean power (kW/m)*	*Maximum power (kW/m)*
1.	Jan.	1.1	3.0	3.4	2.3	16.8
2.	Feb.	0.8	2.0	3.6	1.3	7.9
3.	March	0.7	1.5	2.1	0.6	2.6
4.	Apr.	0.8	2.0	2.8	1.0	6.2
5.	May	1.1	2.5	3.8	2.5	13.1
6.	June	1.7	4.5	4.0	6.4	44.6
7.	July	1.3	3.0	4.4	4.1	21.8
8.	Aug.	1.2	4.0	3.9	3.1	34.3
9.	Sept.	1.1	2.0	3.8	2.5	8.4
10.	Oct.	0.8	1.5	3.7	1.3	4.6
11.	Nov.	1.1	2.5	3.4	2.3	11.7
12.	Dec.	1.3	3.0	4.7	4.4	23.3

Location: *Latitude 12°-15° N; Longitude 81°-84° E.*

Table 8.4: Significant wave height and wave period for Nayachara Island

S. No.	*Wind speed (km/h)*	*Mean wave height at depth*		*Mean wave period(s) at depth*	
		6 m	10 m	6 m	10 m
1.	50	1.08	1.34	4.25	4.50
2.	60	1.24	1.56	4.50	5.0
3.	70	1.36	1.77	4.75	5.25
4.	80	1.47	1.96	5.00	5.50
5.	90	1.58	2.13	5.25	5.75
6.	100	1.69	2.29	5.50	6.0

7.	125	1.93 2.65	6.0 6.60

Location: *Latitude 22°; Longitude 88°7′.*

8.4.8. Wave Energy Conversion

The *wave energy is in the form of motion of water particles.* The potential energy and kinetic energy in water are converted to mechanical energy in the *'wave machine'* (wave energy converter) in the following *two* ways:

1. Wave machine *drives gears and electrical generator.*
2. Wave machine drives *air compressor or hydraulic pump to store energy in tanks, drive another machine for energy conversion.*

The former method/route is preferred as the energy can be transmitted to the shore.

8.4.9. Wave Energy Conversion Machines

Wave machines (or devices) are basically employed for energy conversion from the wave. The fluctuating mechanical energy from wave machine is *modified* to drive a generator.

8.4.9.1. Classification of wave machines:

Wave machines are *classified* as follows:

A. On the basis of location:

1. Off-shore or deep water device.
2. Shoreline devices.

- In *"off-shore wave machines"*, the *cost* of installation, operation and power transmission is *quite large.*
- In *"shoreline machines"* the cost of installation and maintenance is low.

B. On the basis of position with respect to sea level:

1. Floating devices.
2. Submerged devices.
3. Partially submerged devices.

- Submerged and partially submerged machines have the benefit of easier maintenance but have poor or worst storm conditions.

C. On the basis of actuating motion used in capturing the wave power:

1. Heaving float type.
2. Pitching type.
3. Heaving and pitching float type.

4. Oscillating water column type.
5. Surge devices.

8.4.9.2 Float wave-power machine

Wave motion is primarily 'horizontal', but the *motion of the water is primarily 'vertical'.* Mechanical power is obtained by floats making use of the motion of water. The concept visualises a large float that is driven up and down by the water within relatively stationary guides. This reciprocating motion is converted into mechanical and then electrical power is generated.

Fig. 8.16. shows Martin's float wave-power machine.

Construction. It consists of a *'square float'* which moves up and down.

Fig. 8.16: Float wave-power machine.

'Four vertical manifolds' that are part of a platform guide the floats. A *'piston'* attached to the float compresses air in a *'cylinder'* which is stationary with the platform. The piston cylinder arrangement acts as a *reciprocating air compressor.*

Working:

— The *downward motion* of the piston *draws air into cylinder* via inlet check valve. — The *upward motion compresser the air* and send it through an outlet check valve to the four *underwater floatation tanks* via the four manifolds. These tanks serve the dual purpose of buoyancy and air storage tanks and the four manifolds serve the purpose of float guides and discharge air pipes.

— The compressed air in the buoyancy - storage tanks is then used to driver an *air turbine* which in term runs an electric *generator*, and the electricity is transmitted to the shore via underwater cable.

Limitations:

1. Waves are not perfectly sinusoidal.
2. Linear arrays of several kilometres are required to produce 100 MW. 3.
Aspiration of water into intake systems and submersion by large waves. 4.
Water entering turbine.

5. Design to withstand storms.
6. Transmission of power to shore.
7. Marine growth.

8.4.9.3. High-level reservoir wave machine

Fig. 8.17 shows a high-level reservoir machine. In this system an *hydraulic pump* is operated by the motion of *buoy to raise water to onshore reservoir.* The water in the reservoir is made to flow through a *turbo-generator to generate electricity*, and then back to sea level.

Float (buoy)

In Out

Water

Fig. 8.17: High-level reservoir wave machine.

8.4.9.4. Dolphin-type wave-power machine (generator)

This wave-power machine was designed by a research laboratory in Japan. It consists of the following components (Fig. 8.18):

1. A dolphin;
2. A float;
3. A connecting rod;
4. Two electrical generators.

Fig. 8.18: Dolphin-type wave-power machine.

— A *"stationary generator"*, installed on the top of the structure, collects wave energy from the "*connecting rod*" with *rolling motion.* This generator has a *gear arrangement* which *rotates the rotor to generate electric power.*

— The "*buoy*" which is at the other end of the connecting rod float has two motions, namely *rolling motion* and *oscillatory motion*. The *"floating generator"* collects wave energy from the buoy through a gear arrangement and generates electric power continuously.

The power density (P/B) is given by the relation:

$$\frac{P}{B} = 1740a^2 \mathrm{T} \ W/m \quad \text{...[Eqn. (8.21)]}$$

where, P = Power, W

B = Wave width, m

a = Amptitude of the wave, m, and

T = Wave period, *s.*

- The capacity of one dolphin type wave energy generator, normally, is 100 kW.

Example 8.4: *Calculate the installed capacity of a plant consisting of an array of dolphin type wave energy generators installed along a width 450 m. The mean amplitude of the wave is 2.2 m with a period of 9 s.*

Solution. *Given:* B = 450 m; a = 2.2 *m*; T = 9 *s*

Using the relation: $\frac{P}{B} = 1740\ a^2T$, we get: ...[Eqn. (8.21)] $P = B \times 1740\ a^2T = 450 \times 1740 \times (2.2)^2 \times 9 \times 10^{-6}\ MW$ = **34.1 *MW* (Ans.)**

8.4.9.5. Hydraulic accumulator wave machine

In this type of machine *low-pressure water* (at wave crust) is *pressurized and stored in a 'high-pressure accumulator'*, from which it flows through a water-turbine electric generator. — A composite piston is composed of a large-diameter main system and a small diameter piston at its centre. As the wave water enters through the opening, the main piston moves up and down. A closed water loop exists above the small piston. During the *upstroke*, the pressure on the main piston is *magnified*. — The high-pressure water then moves through a one-way valve to a hydraulic accumulator at the top of the generator.

— High-pressure water flows through a hydraulic turbine that drives an electrical generator and is then discharged to a storage chamber *below the turbine*. **8.4.9.6. Nodding / Oscillating ducks wave machine**

Refer to Fig. 8.19. This wave machine was designed by Stephen Salter at Edinburgh university in Scotland.

Fig. 8.19: Nodding /Oscillating wave machine

It consists of several duck-shaped devices (each 25 m long), installed in a *linear width wise array along a line* which is *perpendicular to the direction of wave.*

— When the forward moving wave front strikes the head on the face of the ducks, wave energy is passed on and ducks start to *oscillate.*

— The ratchet and wheel mechanism conduct the oscillating motion of the ducks to the axial shaft. The wave energy is converted to mechanical energy (by the relative motion of the ducks). The shaft drives linkages, gears and the rotor of

electric generator (the overall length of the cylindrical spine varies between 100 to 500 *m*).

8.4.9.7. Oscillating water column surge device

Refer to Fig. 8.20. When a moving wave is constricted, a surge is produced raising its amplitude. Such a device is known as *tapered channel device* (TAPCHAN). It comprises gradually narrowing channel with heights typically 3 to 5 m above sea level.

Fig. 8.20: Oscillating water column surge device.

The waves enter from the wide end of the channel and then propagate towards narrower region. The wave heights get *amplified* until the crests spills over the walls to a reservoir, which provides a stable water supply to a low head turbine.

The arrangement can be implemented successfully at *low tide sites only*. • An off shore boating wave power vessel having TAPCHAN plant on a steel platform is suggested to *make the system insensitive to tidal range.*

8.4.10. Wave Power Development

- The history of wave machines begins with the first patent filed in parts in 1799 by Girard. The proposed plant envisaged a floating moored ship, connected to a mechanism and a pump mounted on the shore by means of a long rod. The ship oscillated vertically and the horizontal movement was prevented by mooring. The oscillating shaft motion was converted to rotary motion by mechanism at the shore; the mechanism drove the pumps.
- During 1890s the wave phenomenon was analysed by physicists and oceanographers.
- During 1910 to 1950, small prototype wave machines of various types were designed on experimental basis in USA, UK, Japan, Canada.
- During 1959, a 5 MW pumped storage system was built. It was abandoned in 1965 as the oil prices were low. The scheme was reviewed during 1976 and a 20 MW scheme was proposed.
- After 1973 oil price rise, several prototype plants of 100 to 500 kW were developed. Wave power engines of small rating (<500 kW) are commercially marketed by Japan for installing on lighthouses, buoys and remote Islands etc. Large pumped storage schemes operated by hydro-turbine pumps by wave energy were commercially successful in Mauritius (1976) for large base load power plant. Such schemes require suitable geographical contours for installing hydro-electric plants and reservoirs.

Wave power development in India:

The National Institute of Oceanography Goa has divided the Indian coastline into six zones, namely A, B, C, D, E, and F (Fig. 8.21), to expedite and identify high wave energy areas suitable for development of power.

Fig. 8.21: Map of wave power zones in India.

The variation (estimated power in kW/m) in wave regime in different zones during different months is given in the table 8.5.

Table 8.5: Analysis of wave power (kW/m)

S. No.	*Zone*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun.*	*Jul.*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
1.	A	3.02	3.73	3.91	4.47	6.98	26.77	39.57	24.84	10.03	2.69	3.58	4.74
2.	B	5.13	5.05	2.24	1.56	6.31	17.21	27.04	17.14	8.15	4.55	3.52	5.40
3.	C	9.26	4.45	4.05	5.50	11.44	18.85	17.69	15.34	10.11	7.21	6.67	7.52
4.	D	5.78	5.13	3.30	3.58	10.60	16.67	14.79	12.57	8.49	7.94	10.98	14.05
5.	E	4.03	1.69	2.35	3.69	11.14	17.24	17.45	16.16	9.18	6.90	9.71	5.62
6.	F	1.24	1.39	3.28	12.34	14.31	11.90	13.24	16.67	16.07	6.28	2.80	1.85

— On the estimates of the distribution of wave energy (*kW/m*) of sea frontage, the potential is seen to vary from 39 kW on the West coast to 15 kW on the East coast. On the basis of an average estimated wave power potential of 15 kW/m and total coastline of about 6000 *m* the total power potential is of the order of 90,000 MW, which is an enormous source of renewable energy which can be harnessed commercially.

8.5. OCEAN THERMAL ENERGY CONVERSION (OTEC)

8.5.1. Introduction

The oceans cover about 70% of the global surface and are particularly *extensive in the tropical zones.* Therefore, most of the sun's radiations are *absorbed by sea water.* Thus *'warm water'* (low density due to higher temperature) on the ocean's surface flows from *tropics towards poles. 'Cold water'* (high density due to low temperature) circulates at the ocean bottom from the *poles to tropics.* Hence, in *tropical regions,* the water temperature is around **5°C** at a depth of 1000 *m*, whereas at the surface, it remains *almost constant at* **25°C** (range being 24°C to 27°C) for the first few metres because of *mixing*; subsequently it *decreases* *and asymptotically approaches the value at the lower level.*

- Power obtained from OTEC plant is *renewable and eco-friendly*. The plant *can operate in remote islands and sea shore continuously*. According to MNRE, the overall potential of ocean energy in India may be in excess of 50,000 MW, and as such there is an enormous opportunity to this renewable source of energy.