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.

8.5.2. Solar Energy Absorption by Water (Lambert's Law of Absorption)

Solar energy absorption by water takes place according to **Lambert's law of absorption** which states:

Each layer of equal thickness absorbs the same fraction of light that passes through it.

Mathematically,

$$\frac{dI_{(y)}}{dy} = \mu I$$

or, $I_{(y)} = I_0 e^{-\mu y}$ ...(8.21) where, I_0 = Intensity of radiation at the surface ($y = 0$), $I_{(y)}$ = Intensity of radiation at depth y from water surface and falls exponentially with depth, and

μ = Extinction or absorption coefficient.

For very fresh clear water, $\mu = 0.05\ m^{-1}$

For turbid fresh water, $\mu = 0.27\ m^{-1}$

For very salty water, $\mu = 0.50\ m^{-1}$

Almost all of the absorption occurs very close to the surface of deep waters. *Owing to heat and mass transfer at the surface itself, the maximum temperatures occur first below the surface*.

- With the *increase in temperature, the density of water decreases;* pure *water at 3.98°C has the 'maximum density'*.
- There will be *no convective currents* between the *'warmer'*, lighter water *at the top* and *'cooler'*, heavier water *at a depth.*

Similarly, heat transfer by thermal conduction between water layers at the surface and a depth is *too low* to alter the picture and the *mixing is retarded.* The 'warm water' stays at the *top* and 'cool water at' the *bottom.*

- In tropical waters there are essentially *"two infinite reservoirs":*

(*i*) A *'heat source' at about* 27°C, and

(*ii*) A *'heat sink'* at about 4°C, at some depth of 1000 *m*.

Both these reservoirs are maintained annually by solar incidence. These temperatures vary with *latitude* and *season.*

Fig. 8.22 and 8.23 illustrate the variation of ocean surface water temperatures with latitude and season.

29

Surface water temperature, °C

28

27

26

25

24

23

22

Jan. F M A M J J A S O N D J Feb. Months

Fig. 8.22: Monthly variation of surface temperature of tropical ocean water.

AVC-4

Ocean Energy

Fig. 8.23: Variation of surface temperature of tropical ocean water with latitude and season.

8.5.3. Working Principle of Ocean Thermal Energy Conversion (OTEC)

The *principle of OTEC is that "there is a temperature difference between water at the bottom of the sea and water at the top", this temperature difference can be used to operate a heat engine.* Most of the radiation is being absorbed at the surface layer of water. The mixing between hot and cold water is prevented because *no thermal convection occurs* between hot and cold water layers. This means that the *surface layer* will act as a *"source"* and *cold layers* act as a *"sink"*. Therefore, it is essential to connect the reversible heat engines between source and cold sink to produce work, that can be converted into required applications.

8.5.4. Efficiency of OTEC

The maximum efficiency of a heat engine working between two temperature limits *cannot be more than that of a Carnot cycle operating between the same temperature limits.* The Carnot cycle efficiency, in the range of temperatures of warm water (T_1) in the upper surface layer and cold water (T_2) in the depth of the tropical ocean, is given by: ...(8.22)

$$\eta_{carnot} = \frac{T_1 - T_2}{T_1}$$

If, $t_1 = 27°C$ or $T_1 = 27 + 273 = 300$ K, and $t_2 = 5°C$ or $T_2 = 5 + 273 = 278$ K, then

$$\eta_{carnot} = \frac{300 - 278}{300} = 0.0733 \text{ or } \mathbf{7.33\%}$$

It is *only a theoretical value, but in actual practical is about* **2%** *only.*

Example 8.4: *Determine the overall efficiency of an ocean thermal energy conversion plant if* *the temperature of water in the surface layer is 26°C and the temperature of cold water in the depth of the tropical ocean is 8°C. Assume the relative efficiency factor of the power plant 0.35.*

Solution. *Given:* $T_1 = 26 + 273 = 299$ K; $T_2 = 8 + 273 = 281$ K;

Efficiency factor, $EF = 0.35$.

Overall efficiency, η_{OTEC}:

$$\eta_{carnot} = \frac{T_1 - T_2}{T_1} = \frac{299 - 281}{299} = 0.06 \text{ or } 6\%$$

$\therefore \eta_{OTEC} = EE \times \eta_{carnot} = 0.35 \times 6 =$ **2.1% (Ans.)**

8.5.5. Types of OTEC Plants

The plants which employ carnot-type process to generate power between the two steady temperatures are called. **Ocean Thermal Energy Conversion (OTEC) plants.** The two basic types of OTEC systems:

1. Closed cycle (or Anderson cycle) system.
2. Open cycle (or Claude cycle) system.

8.5.5.1. Closed cycle (Anderson cycle, vapour cycle) system

The closed cycle OTEC concept was proposed by *'Barjot' in 1926.* The cycle was further developed by '*Anderson' in 1992.*

All the systems being proposed for construction, now work on *"Closed Rankine cycle'* (Anderson cycle, *vapour cycle*) and use low boiling point working fluids like *ammonia, propane, freon (R-12, R-22)* etc. These systems will be *located off-sore on large floating platforms* or *inside floating hulls.*

The *warm surface water* is used for supplying the *heat input* in the *'boiler'*, while *cold water* brought up from ocean depths is used for *extracting* the heat in the *'condenser'*. Fig. 8.24 shows a schematic diagram of a closed or Anderson cycle OTEC plant.

Fig. 8.24: Schematic layout of the closed or Anderson cycle OTEC plant.

Working:

— Warm water from ocean surface is circulated through a pump to a *'heat exchanger'* which acts as a *'boiler'* to generate working fluid ammonia vaour at high pressure. — This vapour expands in the *'turbine'* to develop mechanical power, which in turn runs an electric *'generator'* to produce electric power.

— The working vapour from turbine at low pressure is condensed in the *'condenser'* with the help of cold water drawn from the depth of ocean through a pump. The *overall efficiency* of such a plant is *very low* in the range of 2 to 3% only. Inspite of this, the concept of an OTEC system seems to be economically attractive because both the *collection and storage of solar energy is being done free by nature*.

- The *"major advantage"* of this system is that fluid evaporates at around 25°C and *does not require vacuum pumps.* The pressure at the turbine will be of the order of 9 to 6 bar resulting in compact turbines (Example: In a 1MW plant, the NH_3 turbine will have about 1.1 *m* diameter turbines which is easy to fabricate technically).

The following points about OTEC are worth noting:

1. Each of the possible working fluids *i.e. ammonia* and *propane* has the following *advantages* and *disadvantages:*
   — *"Ammonia"* has better operating characteristics than propane and it is much less inflammable. On the other hand ammonia forms *irritating* vapour and probably could not be used with copper heat exchanger.
   — *"Propane"* is compatible with most heat-exchanger materials, but is highly flammable and forms an explosive mixture with air.

- *Ammonia* has been used as the working fluid in successful tests of the OTEC concept with closed cycle systems.

2. Because of the *low cycle efficiency* the heat to be transferred in the boiler and condenser is *large*. In addition, the temperature difference between the sea water and the working fluid in these heat exchangers has to be restricted to very small values. For these reasons, *very high flow rates are required for the sea water both in the boiler/evaporator and the condenser.* This results in *high pumping power requirements* and is reflected in the gross power outputs which are 20-50 percent higher than net power outputs.

- A second important consequence is that both the evaporator and condenser are *much larger in size than similar components in conventional practice.*
- The materials suggested for these heat exchangers are *titanium* or an *alloy of copper and nickel.* This is necessitated because of the *corrosive nature of the sea water.* 3. An examination of the break up of the OTEC system costs shows that the *cost of heat exchangers* plays an important role in costing; they contribute about *30 to 40 percent of the total*.

8.5.5.2. Open cycle (Claude cycle, steam cycle) system

In this system, the warm water is converted into *'steam'* in an evaporator. The steam drives steam-turbine generator to deliver electrical energy.

Fig. 8.25 shows the schematic layout of open or claude cycle OTEC plant.

Fig. 8.25: Schematic layout of the open or claude cycle OTEC plant.

Working:

— The warm water from ocean surface is admitted through a *'deaerator'* to the *'flash evaporator'* which is maintained under *high vacuum.* As a result, *low pressure steam*

is generated due to *throttling effect* and the remainder warm water is dicharged back to the ocean at high depth.

- The deaerator also removes the dissolved non-condensable gases from water before supplied to the evaporate.

— The low pressure steam having very high specific volume is supplied to *'turbine'* where it expands and the mechanical power so developed is converted into electric power by the *'generator'.*

— The exhaust steam, from turbine is discharged into a direct contact type condenser where it mixes with cold water drawn from ocean at a depth of about 1 to 2 km. The mixture of condensed steam and ocean cold water are discharged into the ocean.

Advantages:

1. The warm ocean water is flash evaporated and the need for having a *surface heat exchanger is eliminated.*
2. The *portable water is obtained* when the exhaust steam from the turbine is condensed.

Disadvantages:

1. As the steam is generated at *very low pressure* (0.02 bar approx.) the *volume of steam* to be handled is *very large,* leading to a *very large diameter for the steam turbine.* (*Example:* A 1 MW OTEC plant requires a steam turbine of 12 *m* in diameter.)
2. To maintain the vacuum in the flash evaporator, massive vacuum pumps will be required.
3. The plant cost is high.
4. The plant is subjected to extremely reverse stresses.

8.5.4.3. Modified open cycle OTEC plant

The efficiency of the open cycle OTEC plant can be increased by making the following modifications:

1. Improved evaporator called *controlled flash-steam evaporator*.
2. Use of *surface condenser* instead of direct contact condenser.
3. Use of plant for *cogeneration of electric power and fresh water*.

Fig. 8.26 illustrates a modified open cycle OTEC, *"Cogeneration plant" which generates electric power and fresh water.*

Fig. 8.26: Modified open cycle OTEC plant.

Working:

— Warm ocean water is fed into the *controlled flash evaporator* via the *ingestor-deaerator.*

— Steam collected from flash steam evaporator is supplied to the *steam turbine. Spent water* from the evaporator is returned to the ocean.

— Steam turbine drives the electric generator and delivers power to the network. — Exhaust steam from the steam turbine is condensed in *'surface condenser'* and *'fresh water' is supplied to users.*

— As the *plant supplies electric power and fresh water, it is a* **"cogeneration plant". —** Cold water from condenser is drawn from deep ocean and after circulating through the condenser tubes the spent water is discharged into the ocean. **8.5.5.4. Hybrid OTEC system**

This system combines the best features and avoids the worst features of the open and close cycle systems.

Working:

— The warm ocean water is *flash evaporated to steam, as in open cycle.* — The heat is then transferred to *ammonia based closed Rankine cycle system.* — The ammonia gas is then fed to the turbine, which is coupled to the generator to generate electricity.

— The ammonia goes to condenser unit and finally pumped to evaporator to repeat the cycle.

8.5.5.5. Thermoelectric OTEC system

This OTEC system was developed by Solar Energy Research Institute Colorado USA, during 1979.

It operates on the *"thermoelectric principle"* which is *simple in construction and economical.* Fig. 8.27. shows a thermoelectric OTEC equipment. It consists of two separate packs, made of semiconductors, and covered by a thin thermal conducting sheet.

Fig. 8.27: Thermoelectric OTEC equipment.

Working:

— The *warm water* from the surface of ocean is circulated over *one device* and *cold water* pumped from the depth of ocean is allowed to flow over *other device.* — The temperature difference of two waters with the solid state semiconductor devices generate the electric power using thermoelectric effect. The *economy* of the OTEC depends on *large variation of water temperature used for the surface and the deep ocean (minimum* 20°C*).*

8.5.5.6. Bio-fouling

Bio-fouling (the deposition and growth of micro-organisms) *is the biological impurity of sea water that deposits and grows on evaporator and condenser metal surfaces, creating thermal resistance for heat transfer.*

The total formulation of bio-fouling, corrosion and so on is referred to a **fouling** (or *scaling*) and will tend to inhibit heat transfer through it.

The *fouling factor* is a measure of the thermal resistance of a fauling film. Provisions must be made to *inhibit* the formation of fouling layers on the surfaces of OTEC heat exchangers etc. This can be accomplished by periodically cleaning the heat exchanger surfaces through *mechanical, chemical or other means*.

8.5.6. Advantages, disadvantages / Limitations and Applications of OTEC

Following are the *advantages, disadvantages, limitations* and *applications* of OTEC:

Advantages:

1. It is clean form of energy conversion.
2. It does not occupy land areas.
3. No payment for the energy required.
4. It can be a steady source of energy since the temperatures are almost steady.

Disadvantages / Limitations:

1. About 30 percent of the power generated would be used to pump water. 2. The system would have to withstand strong convective effect of sea water; hurricanes and presence of debris and fish contribute additional hazard. 3. The materials used will have to withstand the highly corrosive atmosphere and working fluid.
4. Construction of floating power plants is difficult.
5. Plant size is limited to about 100 MW due to large size of components. 6. Very heavy investment is required.

As an **example** for a 150 MW plant:

— A flow of 500 m^3/s would be required;

— The heat exchangers area required will be about 0.5 km^2;

— A cold duct of 700 m length with a dia. of 25 m would be required.

Applications:

1. A closed cycle OTEC plant can also act as a chemical treatment plant. 2. An OTEC plant can also be used to pump up the deep ocean water and this cold water may be used for cooling houses, air-conditioning systems etc. 3. The enclosing area of OTEC can be used for aquaculture and mariculture. 4. The deep ocean cold water is rich in nutrients and can be used for various applications.

5. OTEC plants are quite suitable for cogeneration of electricity and fresh water. • OTEC power generation is a multipurpose project producing and supplying several useful products, like the river valley multipurpose projects.

8.5.7. Development of OTEC Plants

- In 1979, the first OTEC power plant was installed in the Hawai state of the USA:
  - — It was a prototype 50 kW floating plant operated on *closed Rankine cycle* principle with NH_3 as the working fluid.
  - — It was designed with the ocean water temperature difference of 21°C. — The *net power available was only 15 kW,* as 35 kW was consumed in pumping the warm and cold water.

- In 1981, another plant was installed in Nauru (Japan) in the Central Pacific ocean.
  - — It was on-land plant and was economical in construction.
  - — It required a 945 *m* long pipeline for pumping cold water.
  - — Its gross power capacity was 100 kW, operated with a sea water temperature difference of 21.7°C. The net output power was 31.5 kW.
  - — The turbine used was an axial flow type with 3000 rpm, the generator was directly coupled and supplied power at 415 V, 50 Hz.

Development of OTEC in India:

The National Institute of Ocean technology is implementing the world's first 1 *MW floating OTEC technology demonstration project off the Tutocorin coast in Tamil Nadu.* — The various subsystems for the plant have been configured, designed and integrated on an OTEC floating barge.

— A 1 km long cold water pipe has been towed to the site and deployed vertically with an *anchoring system at a depth of 1.2 km.*

- The resource potential of India is estimated around 180×10^3 MW.

8.5.8. Environmental Impacts of Wave Power

The *"Wave power"* is *essentially non-polluting*. No appreciable environmental effects are forseen from island floating wave power devices.

— Onshore wave energy installations may *change visual landscape and degrade scenic ocean front views.* It may also *cause disturbance to marine life* including changes in distribution and types of life near the shore.

— There is *possible threat to navigation* from *collision due to low profile floating wave devices.* It would usually be both possible and necessary to avoid hazards to, or from, marine traffic by judicious planning and by the *provision of navigation aids*.

"Tidal energy" is a renewable source of energy, which *does not result in emission of gases responsible for global warming or acid rain associated with use of fossil fuels.* — Changing tidal flow by *damming a bay or estuary could,* however, *result in negative impacts on aquatic and shoreline ecosystem, as well as navigation and recreation.* • Studies have shown that the *environment impact at each site is different,* and *depends amply upon local geography.*

8.6. MINI AND MICRO HYDEL POWER PLANTS

8.6.1. Introduction

Small hydropower is *covered in the renewable energy power.* It can supply, in principle, significant amounts of electricity for:

(*i*) Irrigation; (*ii*) Portable water pumping; (*iii*) Lighting; (*iv*) Health; (*v*) Educational purposes, etc.

In order to meet with the present energy crisis *partly*, a solution is to develop **mini** *(5 m to 20 m head)* and **micro** *(less than 5 m head)* hydel potential in our country. The low head hydropotential is scattered in our country and estimated potential from such sites could be as much as 20,000 MW.

By proper planning and implementation, it is possible to commission a small hydro generating set-up of 5 MW with a period of one and half year against the period of a decade or two for large capacity power plants. Several sets upto 1 MW each have been already installed in Himachal Pradesh, UP, Arunachal Pradesh, West Bengal and Bhutan.