Chapter 17
Challenges in Ocean Energy Utilization

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Abstract Ocean is a reservoir of energy. It is not only pollution free but also renewable, sustainable and long-lasting than any other known source of energy. Development of suitable cost effective technologies for power generation from different forms of ocean energy (like wave energy, tidal energy, Ocean Thermal Energy Conversion, Marine wind power, Power from marine currents, Marine biomass, Salinity gradient, etc.) is challenging. Three to four decades of R & D works around the World improved the hope for technical feasibility of ocean energy conversion. Increase in the cost of fossil fuel is indirectly supporting more focused research on ocean power plants. It is hoped that more pilot plants will be installed at various oceanic locations in order to understand and solve the challenging technical problems, which may lead to commercial exploitation of ocean energy. Construction of structures and systems for ocean energy conversion is prohibitively expensive. Different methods are developed to reduce the cost of construction like, impact force reduction techniques, new materials for longer life, etc. This chapter discusses the different forms of ocean energy, physics of energy conversion, and the technical challenges involved in the technology development.

17.1 Introduction

Reducing the impact of climate change on various issues like sea level rise, ozone depletion, more frequent hurricanes, ocean acidification, severe rainfall and droughts etc., has become a daunting task of all the countries all over the World. It is possible, only if the greenhouse gas emission is reduced significantly. Hence it is urgently needed to move towards green power from natural renewable resources

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like solar, wind, ocean etc. Ocean is one of the pollution free and inexhaustible sources of energy. The R&D is in progress around the World for the development of technically feasible and economically viable methods to convert the various sources of ocean energy into usable form of energies. Commercial production of tidal power was started at few places around the World. Experiments with mini Ocean Thermal Energy Conversion (OTEC) systems were also carried out by few countries. Few wave energy pilot plants were built and studied. Mini-Commercial OTEC and wave power plants at few places around the World are expected to be installed in the near future.

World population is expected to reach ten billion during 2050 (http://www.treehugger.com/World-Population-Growth-2050.JPG). The World's energy demand also is expected to increase from 15,000 to 27,000 GW by 2050. Renewable energy from the Ocean can support these increased demand, if collective focus is made for commercial exploitation of different forms of energy from the oceans.

17.2 Ocean as an Alternate Energy Source

Energy resources play an important role in the economic development of any country. During the present days of energy crisis, the need for energy conversion as well as the urgency to locate sources for renewable energy is obvious. Solar radiation which sustains life on the Earth is continuous and inexhaustible. It has been estimated that about 10^{16} W of solar energy reaches the Earth. The ocean, which covers about 71 % of the Earth's surface acts as a natural collector of much of this energy. Thus, the ocean has an enormous potential to supply energy in many different ways. The major advantages of ocean energy are that it is renewable, continuous throughout the year and pollution free. For remote islands, ocean energy will be the most suitable form of alternative, since it comes from the immediate vicinity.

17.3 Various Forms of Ocean Energy

The various forms from which the ocean energy could be tapped are:

- Ocean thermal energy conversion
- Wave Energy
- Tidal Energy
- Energy from Marine currents
- Offshore wind energy
- Marine biomass conversion
- Salinity gradient energy

The global distribution of ocean power technologies is shown in the Fig. 17.1. (http://www.geni.org/globalenergy/library/technical-articles/generation/tidal-wave-ocean-energy/energycentral.com/The-Potential-of-Ocean-Power/Marine_Small.gif).

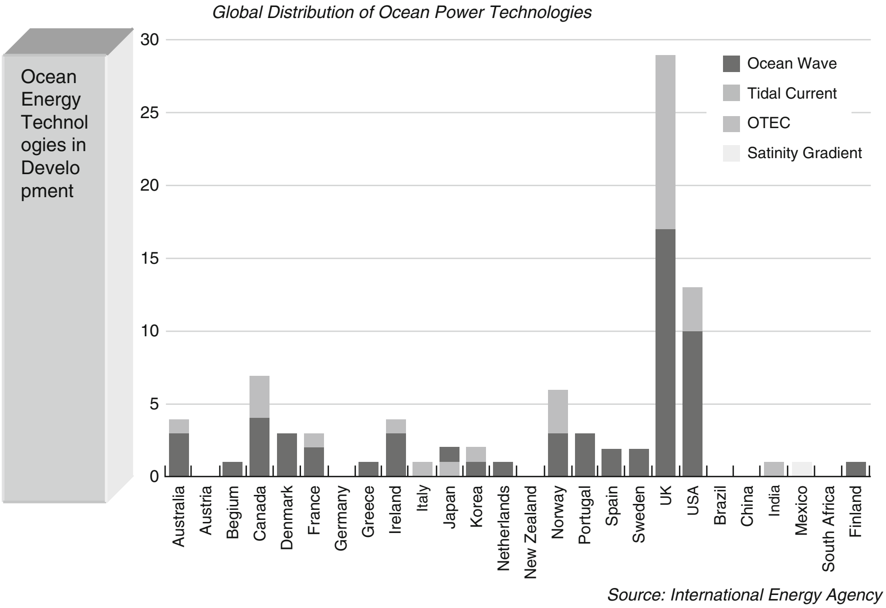

Fig. 17.1 The global distribution of ocean power technologies

17.4 Ocean Energy Potential Around the World and in India

The theoretical estimates (Charlier 1982) for various forms of Ocean power in MW are as follows:

OTEC: 40,000 × 10^6
Salinity gradients: 1,400 × 10^6
Marine bioconversion: 10 × 10^6
Marine current: 5 × 10^6
Wave energy: 2.5 × 10^6
Tidal energy: 3 × 10^6
Offshore winds: >20 × 10^6

17.5 Basic Reasons for the Slow Development of Ocean Energy Conversion Technology

One of the main reasons for the slow development of the technology for ocean energy conversion is that the structures to be built in the ocean accommodating the ocean energy power plant are very expensive with low returns. During the late 70’s large projects were undertaken in the developed countries in developing the technology for the ocean energy conversion system. These initiatives were undertaken principally due to geopolitical reasons and oil-crisis. But in the 80’s, the

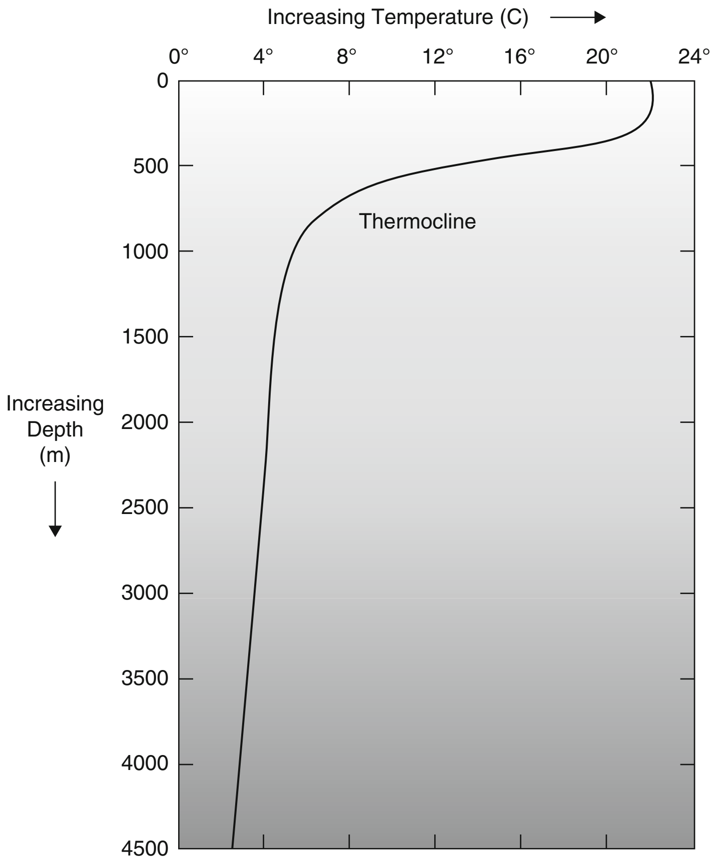

Fig. 17.2 Thermocline in the ocean

international oil prices started decreasing and the enthusiasm in the technology development in ocean energy suddenly dropped. Construction of pilot plants to prove the technology and to understand the technical problems is cost intensive. Private organizations hesitate to invest the money for such basic research. In developing countries, government does not have enough money to invest on such research and development activities due to other priorities and commitments. The technological development relating to OTEC, tidal and wave energy, and the prospects for commercialization in the near future are discussed below.

17.6 Ocean Thermal Energy Conversions (OTEC)

17.6.1 Principles and Prospective Locations

OTEC utilizes the temperature difference between warm surface sea water (that normally ranges between 24 °C and 28 °C) and the cold deep sea water with a range of 5–7 °C (Fig. 17.2 – http://marinebio.org/Oceans/Temperatures.asp), available at

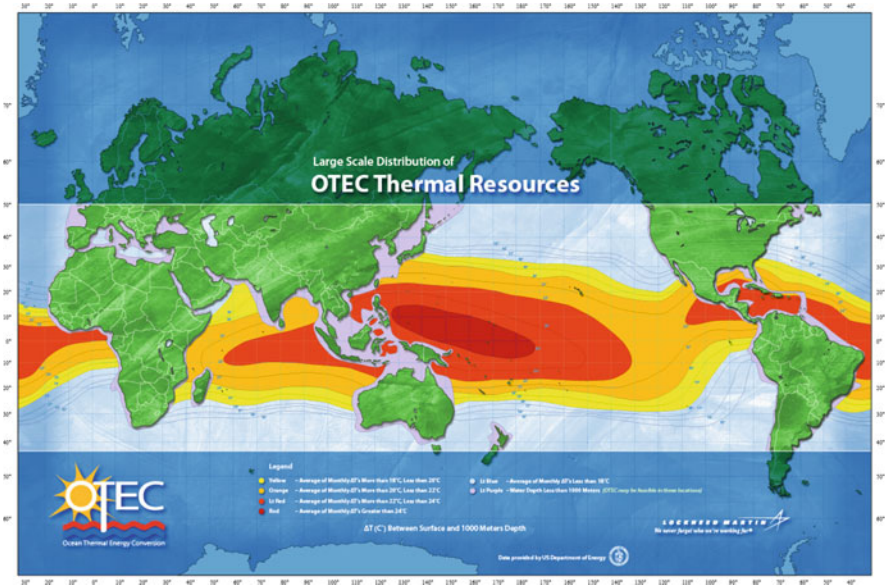

Fig. 17.3 Temperature difference of seawater between surface and depth of 1,000 m (Source: http://www.lockheedmartin.com/us/products/otec.html)

depths of 800–1,000 m. It is attractive for countries located in between the Tropic of Cancer and the Tropic of Capricorn (Fig. 17.3) (http://www.nrel.gov/otec/images/illust_gradient_map.gif). The warm water overlies the colder water at depths of about 1,000 m near 30 °S and 30 °N. Near the equator, the colder water lies at a depth of about 100 m itself. About 90 % of the surface area is occupied by ocean between 30 °S and 30 °N.

17.6.2 Two Alternative OTEC Systems

Open Cycle uses sea water as the working fluid. The warm surface water is flash-evaporated in a chamber maintained under high vacuum and the vapor generated is utilized to drive a low pressure turbine connected with the generator. The exhaust steam is condensed using cold sea water (Fig. 17.4) (http://electronrun.files.wordpress.com/2008/02/otec-2.jpg).

The Closed Cycle system utilizes a low boiling point liquid like Freon or Ammonia as the working fluid. The fluid is evaporated using the warm surface sea water. After the vapor drives the turbine, it is condensed by cold sea water. This condensate is pumped back to the evaporator (Fig. 17.5. – http://saveourbeaches.org/wp-content/uploads/2008/11/oceanenergy11.jpg).

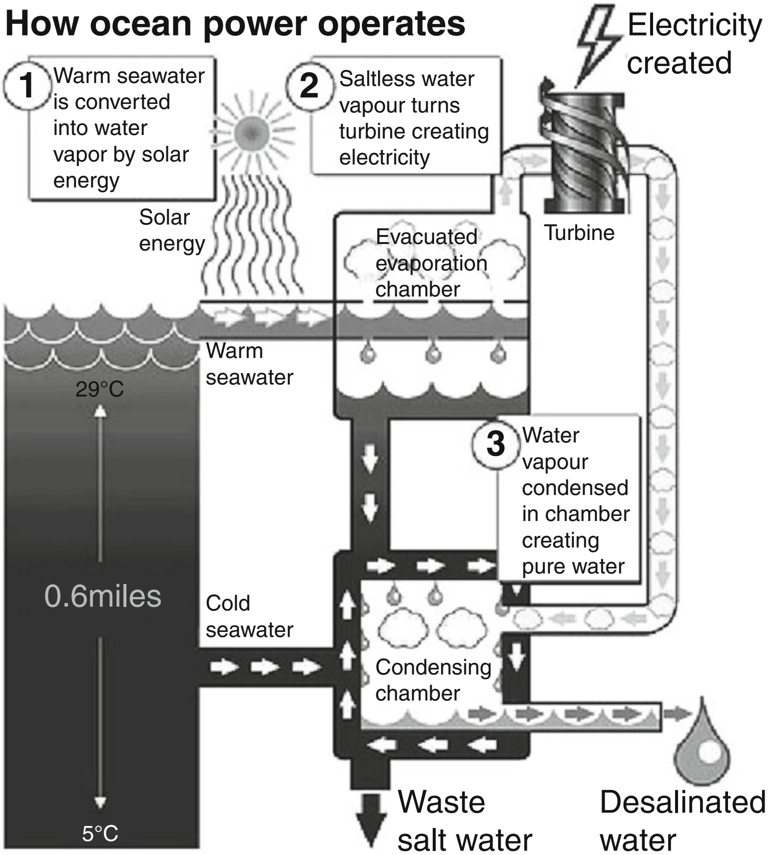

Fig. 17.4 Open cycle OTEC system

17.6.3 Location of OTEC Systems

Depending upon the availability of deep sea near the coast, the OTEC system could be installed in three types of locations.

- If the distance of deep sea from coast is large, then the OTEC plant could be placed on a floating platform with a cold water pipe suspended from it. An underwater cable is needed for power transfer to the shore. Alternately, the generated power may be utilized to produce energy intensive materials like Ammonia or hydrogen from the sea water. The products have to be transported to the main land by ships.
- If the distance is around 10 km, the OTEC plant could be fixed in the near shore area and the generated power can be transmitted to the main land by underwater cables.
- If the deep water conditions are available within 2–3 km of the coast, the entire plant could be situated on land with the cold water pipe line running along the ocean bed to a depth of 800–1,000 m.

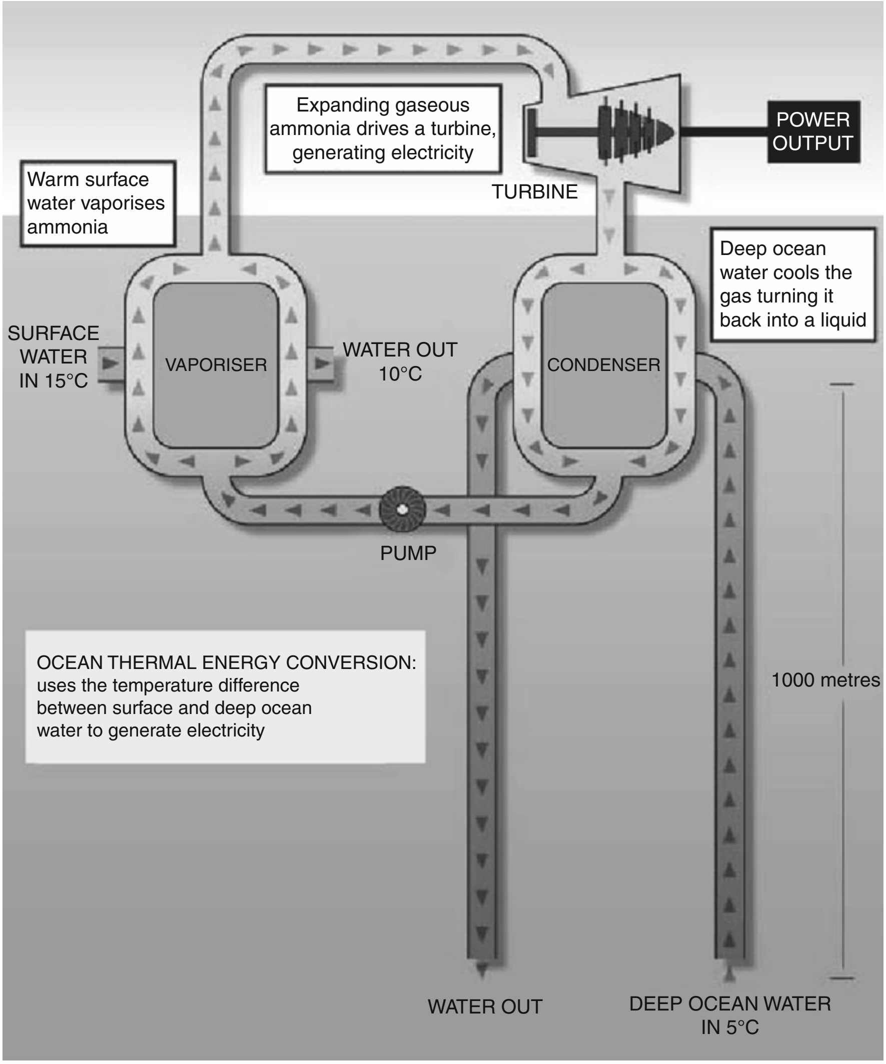

Fig. 17.5 Closed cycle OTEC system

17.6.4 Advantages of OTEC Systems

- Power from an OTEC system is continuous, renewable and pollution free.
- The cold deep sea water is rich in nutrients and can be utilized for aquaculture.
- An open cycle OTEC system provides freshwater as by-product. The closed cycle system can also be combined with a desalination plant to get freshwater.
- OTEC is an important alternative source of power for remote islands.

- A floating OTEC plant could generate power even at mid-sea, and be used to provide power for operations like offshore mining and processing of manganese nodules.
- The power from the OTEC plants in the mid- sea can be used to convert the sea water into Hydrogen, Ammonia and magnesium.

17.6.5 Global Technology Development

The basic concept of OTEC was proved on a very small scale about 80 years back by George Claude (1930). In USA, a 50 kW demonstration plant named ‘Mini OTEC’ was deployed off Hawaii in August 1979 and operated for 4 months. Another demonstration plant, off Hawaii known as OTEC-1, was installed to test heat exchangers for 1 MW energy. An old ship was converted to a floating platform to house shell and tube type of heat exchangers. A 1.2 m diameter cold water pipe was installed to a depth of 650 m. The experimental results for the condenser and the evaporator agreed excellently with the theoretical predictions. Ammonia was used in the system as working fluid. The experiments were completed in March 1981.

At about the same time, French Scientists had a three phase programme. The first phase (1979) was a feasibility study for a 10 MW power plant. The second phase (1982) was for the selection of a specific working system, testing of major components and site studies. The third phase (1985) was for the design of a 5 MW pilot plant for Tahiti Island but was finally abandoned.

In Japan, development of OTEC began in during 1970–71. Initially, feasibility studies and conceptual design of large commercial 100 MW (four numbers of 25 MW modules) floating plants were undertaken. Japan has built a 100 kW mini demonstration plant successfully and operated on the Pacific Islands of Nauru from September ‘81 to September ‘82. The entire plant was on land with the cold water pipe line running to a depth of 700 m. A large number of Universities, national government agencies and private companies actively involved in research and development for installation mega size OTEC plants in Japan.

During 1993 in Hawaii, near Kona’s Keashore Airport, the construction of a land based 210 kW open cycle OTEC power plant was carried out at a cost of \$12 million. This facility has demonstrated the feasibility of the low pressure open cycle turbine and high efficiency vacuum compression subsystems. Based on the experience gained, it was planned to go for 5 MW demonstration plants followed by 100 MW commercial plants.

In India, National Institute of Ocean Technology, Chennai, tried for 1 MW pilot plant in Bay of Bengal. Further studies are in progress.

17.6.6 Commercialization of OTEC

OTEC is capital intensive. OTEC can be viable in certain parts of the World, if additional users are found for the water pumped from the ocean bottom for aquaculture. The energy analysis of the OTEC system indicated the pay- off times from 4.7 to 6.2 years. It is concluded by research community that OTEC power plant system is one of the most attractive alternatives for solving the future electrical energy needs.

Until operational experience is gained on larger size OTEC plants and economic performance verified through commercial demonstration of OTEC technology, uncertainty would loom over investment and participation from private sector. A consensus exists among the various investigators that OTEC now stands at the transition between technology development and application. It will take some more time for the implementation of full fledged commercial level OTEC plant in the order of 100 MW.

17.7 Wave Energy

17.7.1 General

The ocean waves are an inexhaustible source of energy. About 1.5% of the solar energy is converted into wind energy. A part of the wind energy is transferred to the sea surface resulting in the generation of waves. This energy, if tapped economically, can meet a sizable portion of world's energy needs. Extraction of energy from waves is more efficient than collection of energy from the wind, since the wave energy is much concentrated (Ravindran and Koola 1991). The wind energy, transferred to large sea surface is stored as mechanical energy in waves. The inertia of the waves provides this short time storage and also tends to smooth out part of the high variability of wind power. The wave energy potential varies widely depending upon the geographic location (http://www.ceto.com.au/about/images/tn-global-wave-energy-map.png). Even at a given place, the energy availability varies during the different parts of the day, for different months and from season to season.

17.7.2 Estimation of Wave Energy Potential

The power available in the Ocean wave per m length of wave crest is expressed as

$$P = 0.55\, {H_S}^2 T_Z \text{ kW} \tag{17.1}$$

where, H_s is the significant wave height (m) and T_z is the average zero crossing period (sec). A wave condition with $H_s = 2$ m and $T_z = 7$ s posses a power of about 15 kW/m of the wave crest. The average wave height in areas near the equator is much less compared to areas under the northern latitude. A wave power potential of about 60–80 kW/m have been reported in the north Atlantic and North Sea areas. The annual average wave height along the Indian coast is 1.0–2.0 m with average wave period from 6 to 10 s and hence the annual average wave power is between 5 and 15 kW/m.

17.7.3 Types of Wave Energy Convertors

There are three kinds of approaches which have been used to harness the wave energy; viz. Buoys or Floats, Oscillating Water Columns and Focusing Devices (Shaw 1982).

17.7.3.1 Buoys or Floats

Floating buoys have been developed to generate energy from the heaving motion caused by the waves. Vertical buoys can also be used in a similar manner to move a piston up and down which contains a permanent magnet. The magnet is surrounded by a copper wire coil. As the magnet moves back and forth through the coil, an electric current is generated. One of the advantages of this approach is that the current is produced directly without the need of a generator. The buoy approach can be used with both vertical and horizontal types of buoys. An example of a horizontal buoy is the Pelamis wave energy converter (http://www.mywindpowersystem.com/2009/09/ocean-wave-energy-alternative-energy-part-7/) which uses semi-submerged cylinders linked by hinged joints. It looks a lot like a sea serpent in the water and so was named after the Pelamis sea snake. Inside each cylinder, there is a hydraulic ram which pumps high-pressure oil through hydraulic motors. The hydraulic motors in turn drive electrical generators inside the cylinder. Many of these cylinders can be combined and then the energy can be fed to an underground sea cable and back to shore.

17.7.3.2 Oscillating Water Columns

Another approach to generate energy from waves is to use a water filled column in which the rise and fall of the water in the column moves air or fluid which in turn spins an electrical generator mounted at the top of the column (Fig. 17.6 – http://www.ocean.com/article.asp?resourceid=3718&catid=5&locationid=2).

17.7.3.3 Focusing Devices

A third approach is to use channels near the shore to the wave energy into an elevated reservoir. Then as the water flows back out of the reservoir a standard hydroelectric water turbine is used to generate electricity (http://www.rise.org.au/info/Tech/wave/index.html). There were a number of projects in the 1970's which tried to use this approach but they ran into both funding and technical problems. These early projects underestimated the amount of damage that could be done to the system by storms and salt corrosion. A proper site selection strategy, precautions against seasonal calamities and use of corrosion-resistant materials could make this system viable.

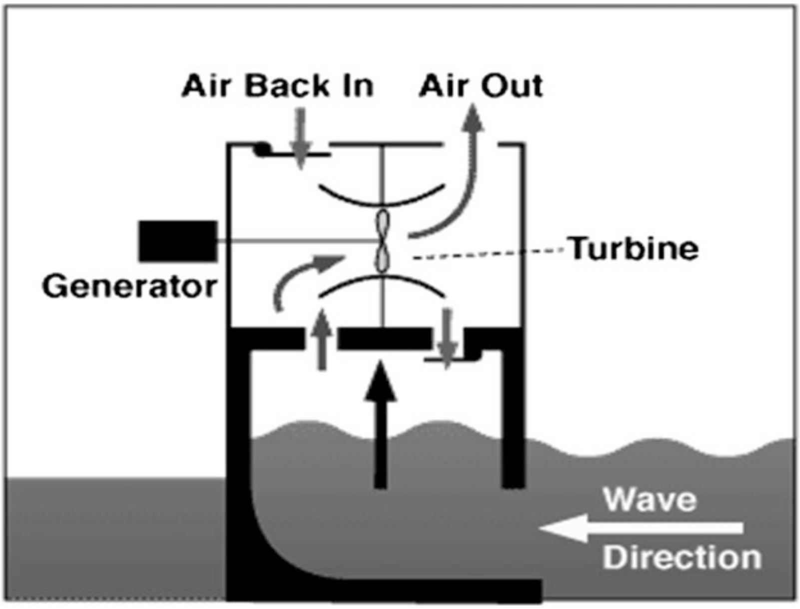

Fig. 17.6 Oscillating Water Column (OWC) type wave energy converter

17.7.4 Pros and Cons of Wave Energy Generation

Water by its very nature is capable of transferring a great deal of kinetic energy as compared to wind energy systems. Consequently, even small wave energy device can produce a great deal of energy. Also, wave energy devices are usually low profile and so do not provide much of a visual distraction if placed off-shore. A big advantage of wave energy is simply its potential. Our planet is mostly covered by ocean and so the capacity for waves as a renewable energy source is enormous.

As with all renewable energy technologies, wave energy has its share of challenges. Initial attempts at using wave technology often failed because ocean environments are inherently changeable. Storms can quickly cause waves to go from a couple of feet to 40 or 50 ft in a matter of hours. Consequently any wave energy device must be made incredibly durable in order to survive harsh ocean conditions. Another major drawback of wave energy systems is that they are either in the ocean or offshore which means that any electricity which is generated must be transferred, usually via undersea cable back to land where it can be used. The laying and maintenance of the electric cables can add significantly to both initial costs and maintenance costs.

17.7.5 Global Technology Development

United Kingdom and Japan are the pioneers in harnessing technology to utilize the wave energy, while Portugal, Ireland, Norway and the USA also have started serious R & D activities. Few hundreds of patents have already been registered on different types of wave energy devices. Commander Masuda of Japan was the first to develop the Oscillating Water Column (OWC) system with air turbine to light navigational buoys. This concept was extended for large scale power generation and later it became a joint effort between UK and Japan. The OWC system with the air turbine was subjected to sea trial in the Sea of Japan in October 1979. Development at the National Engineering Laboratory, Glasgow, UK, showed that the bottom seated system had better power absorption ability and lesser maintenance cost compared to floating systems. Additionally, the installation and maintenance of mooring systems are expensive. The National Engineering Laboratory used conventional axial flow air turbine with four valves for rectifying the flow. Prof. Wells of Belfast University, UK, has developed a turbine which will rotate in the same direction with pulsating air flow in and out of the system and does not require any valves. A wave energy power plant of 500 kW capacity was built by M/s. Kvaerner Brug of Norway at one of the Fjords along Norway's west coast at a water depth of 60 m. The system had a Well's turbine of 2 m dia. This system worked satisfactorily for a period 1 year before it was knocked down by 20 m high cyclone waves during December 1988. An offshore device was built during the year 1990 by Japan as a part of their breakwater in Sakata port. Based on the OWC Principle, a concrete caisson in a rock gully was built at Isle of Islay off the west coast of Scotland and a biplane Well's turbine with a capacity to generate 75 kW was installed in 1990. The wave energy group at Queens University, Belfast, have carried out necessary measurements and evaluated the performance of the system. In 1991, the Commission of the European Communities decided to launch, some preliminary R & D actions in wave energy. One of these actions was to investigate the location and design of a medium scale shoreline oscillating water column pilot plant to serve as a European platform for research into aspects of wave energy devices at practical scale, particularly in problems associated with air-turbines, primary control systems, power take-off systems, electrical control systems, grid interaction etc. This action was undertaken by Institute Superior Technico, Lisbon in Portugal, Queen's University, Belfast in Northern Ireland and University College, Cork, Ireland in conjunction with a variety of subcontractors. The wave resource assessment and the survey of suitable sites in Portugal, UK and Ireland were carried out by the teams, which finally selected three sites namely, The island of Islay in the United Kingdom, The Old Head of Kinsale in Southern Ireland, and The island of Pico in the Azores for the construction of pilot plants.

The European plant on Islay demonstrates the 'designer gully' method of construction in which, the water column structure was built in a man-made recess in an otherwise straight length of coastline. The plant in Pico utilized a natural rock gully and demonstrates a more advanced form of the construction.

Japan has considered a variety of wave energy converting systems like pendulum type at Muroran Port of Hokkaido, Wave power generating system with a constant air pressure tank at Kujukuri beach, Pneumatic wave power conversion system with water valve rectifier in the breakwater of Haachi Fuel Station and floating wave power device "Mighty Whale" at the offing of Gokasho Bay of Mie.

Fig. 17.7 Indian wave power pilot plant in Vizinjam, Kerala

The progress of research and development in Japan is remarkable. The Japanese are also of the opinion that the most economical device is the wave power extracting caisson breakwater. But they also confirm that the present day electricity cost from wave power is expensive compared to the conventional power. Further research and development is needed to economize the commercial wave power plants.

17.7.6 Wave Energy: Multipurpose Concept

Wave energy potential along the Indian coasts is not as high as that of the northern latitude countries. Therefore, a wave energy system only to generate electricity may not be commercially viable in the near future. However, there are many other utilities that may arise by regulating the waves. A multi-purpose wave regulator system has been proposed by the Wave Energy Group, IIT-Madras, with the following objectives (Ocean Energy Cell 1989):

- Replace a part of the rubble mound breakwater by caissons and hence save the cost to be spent for rubble mound breakwater.
- Use the Caisson for berthing and hence save the cost of construction of a separate berthing structure.
- Absorb the wave energy and convert it into usable form of energy.

17.7.7 Wave Energy Study in India

The Department of Ocean Development (DOD), Government Of India, has supported the wave energy group of IIT Madras to investigate one such type of system. The initial objective was to identify a suitable wave power absorbing system and location for the installation of 150 kW capacity pilot plants (Fig. 17.7) (http://www.niot.res.in/projects/desal/desalination_waveenergyin.php). Based on laboratory and theoretical investigation, the bottom fixed oscillating water column type caisson with projecting side wall was selected for field testing. Vizhinjam off Trivandrum was identified as suitable site for construction. Consequently developmental activities were concentrated on this device.

A concrete caisson of dimensions 23 × 17 m in plan and 18 m high weighing about 3,000 t and housing an Oscillating Water Column has been constructed in floating mode, towed and seated on a prepared rubble bed foundation. On top of this caisson, a vertical axis Well's turbine of 2 m diameter coupled to a 150 kW induction generator was mounted. The caisson is connected to the top of the breakwater of the harbor by a steel bridge. This system has been commissioned on October 1991 and performance monitoring was carried out.

A data acquisition system has been developed to monitor the variation of all these dynamic pressures. The power plant is being run periodically for monitoring the performance of the various sub-systems and the system as a whole.

17.7.8 Further Indian Wave Energy Activities

Techno-economic feasibility studies were carried out for incorporating 15 numbers of wave energy caisson modules for a total installed capacity of 1.5 MW for Thangassery fishing harbor near Quilon in Kerala state and 1.0 MW system for Musbay in Car Nicobar Islands (Neelamani et al. 1995).

17.7.9 Commercialization of Wave Power Plant

The recent wave power technological developments in India and Japan show that in near future the cost of production of wave power can be comparable to the conventional power production, if other benefits of the breakwater type caissons are also suitably considered while estimating the cost/benefit ratio. The cost of wave power is site specific. For example, it is estimated that the wave power production cost during 1995 for islands like Andaman, Nicobar and Lakshadweep was about $0.195/kWh (Neelamani et al. 1995) compared to $ 0.20 per kWh generation costs from diesel generators. It is expected that the costs of construction and implementation reduce with improved technology. The commercialization of wave power expected to be a reality in the near future.

17.8 Tidal Energy

The tide is the harmonic raising and falling of the ocean water surface due to the attraction of the Moon and the Sun on the Earth and the rotation of the Earth. The average tidal height at mid ocean is only of the order of about 0.5 m. But near the coast, its height varies due to the variations in the sea bed contour, resonance of tidal waves and the configuration of the coast. In some places the tidal range is as high as 14 m (*for example:* Bay of Fundy in Canada). The tidal power plants are

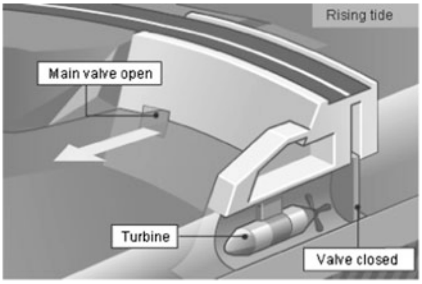

Fig. 17.8 Water entering into the reservoir during rising tide

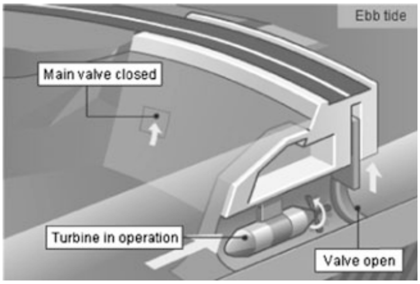

Fig. 17.9 Power generation during ebb tide

similar to the hydroelectric power plants. The major difference is that the tides are periodic with a period of about 12 h 25 min. The water is captured in a reservoir during high tide (Fig. 17.8 – http://www.planete-energies.com/content/renewable-energies/energy-future/oceanenergy/tidal-power.html) and is allowed to pass through turbines and generates power (Sharma 1987) when the tide level falls in the open ocean side during ebbing (Fig. 17.9).

17.8.1 Estimate of Tidal Energy

The energy potential of a tidal power plant, estimated by assuming that power could be developed both during the flood and ebb tides using one basin are given by

$$E = 0.017\,R^2\,S \tag{17.2}$$

where $R =$ tidal range (m), $S =$ Area of basin (m^2). The unit of E is kWh/Year.

17.8.2 Global Potential and Development

Tidal development has gone through long stages of development. There are 27 major tidal power plants located at various places of the World. The first one to go into commercial production is the Rance plant in France (http://energy.saving.nu/hydroenergy/tidal.shtml). About 350,000 m^3 of concrete and 16,000 m^3 of steel were used for the construction of this plant. The area exposed to the sea water is about 90,000 m^2. The construction work was carried out inside a 10 ha cofferdam protected area. It is operational since 1966 and the installed capacity is 240 MW. A mini experimental plant of 400 kW was tried at Kislaya Guba in Russia during 1968. A number of multi-purpose projects along the coast of China have incorporated mini tidal power plants. As many as 128 mini tidal power plants are currently in operation, producing electricity, with a total capacity of 7,638 kW. In spite of this fact, more plants have not been built because the tidal power plant construction is highly capital intensive. Seven estuary projects in UK and Bay of Fundy project in Canada are under various stages of progress.

17.8.3 Tidal Power Potential in India

Three sites in India have been found to be suitable for tidal power development. The Gulf of Kutch and the Gulf of Cambay on the west coast of India have maximum tidal ranges of around 11 m and annual average of around 6 m. In the Sundarbans area of West Bengal, the annual average is around 3.5 m. A study conducted in 1975 by an U.N. expert, E. Wilson indicated a possibility of installing very large tidal power station in the Gulf of Cambay, and Kutch and smaller power stations in the Sundarbans area. Installed capacities of about 7,300, 1,000 and 15 MW in the Gulf of Cambay, Gulf of Kutch and in Sundarban areas respectively are possible. The corresponding estimated costs (1975) are Rs.1,925 crores, Rs.600 crores and Rs.15 crores respectively. The Gulf of Cambay scheme may require a barrage of 40 m height and about 30 km long.

Realizing the great potential in Gujarat, the Central Electricity Authority of Government of India and Gujarat State Government jointly took up a detailed project study in collaboration with Electricite de France, the pioneer who built the Rance Plant. The construction of a power plant of about 800 MW rating is awaiting clearance from the Government of India.

The West Bengal renewable energy agency has expressed interest to carry out a feasibility study for a mini tidal plant in Sundarban area. The chosen site in Durgaduani Creek has a mean tidal range of 4.15 m. A single pool system with two barriers is under consideration. National Institute of Ocean Technology and Indian Institute of Technology, Madras have carried out a Techno-Economic feasibility study for this site. The plant capacity is 3.5 MW. The estimated annual power production is 5.5 million kWh. The life of the system is considered as 50 years. It is estimated that the present day cost of the tidal power for this location is $ 0.1 per kWh.

17.8.4 Commercialization of Tidal Power Plants

Already commercial level tidal power plants are in operation throughout the World. For example: La Rance, Brittany, France, Kislaya Guba, USSR, Annapolis, Nova Scotia, Canada, Jian Xia and Zhehiang Province, China. Of all the methods of extracting energy from the oceans, tidal power enjoys the greatest level of proof of practicability from small to mega project scale. The features that favor tidal power schemes are:

- The tidal power is regular from year to year with less than 5 % variation.
- The tide is accurately predictable and hence the tidal power potential and average annual power are sustainable.
- The tidal power is inexhaustible and pollution free.
- The life of plant is of the order of 75–100 years
- The technology of power production is simple, similar to hydro-electric power stations.
- Improved construction technology like prefabricated plant can be used effectively.

The initial cost of construction of any tidal power plant is prohibitively high. But the maintenance cost is relatively low. The quantitative recognition of the benefits other than the tidal power is essential for cost/benefit analysis. A tidal range of 3–4 m is considered viable for installing a tidal power plant. But there are several sites around the World having a tidal range of more than 10 m. A number of commercial tidal power plants are expected to be installed throughout the World in the near future. The technological feasibility of both major and minor tidal power schemes has been proven. The environmental impact, not withstanding some reservations, is limited; in many sites the economic and sociological consequences are very favorable. Further improvements in construction, civil works, turbine design and other facets will increase price competitiveness. Already the cost of building a nuclear plant is closer to those of tidal power plant whose life span is furthermore longer. The furtherance of tidal power remains a matter of economics and perhaps of politics as well.

17.9 Conclusions

In order to reduce the impacts of climate change, it is a must to increase renewable energy production and reduce burning of any form of hydrocarbons. Apart from solar and wind energies, ocean has tremendous potential as renewable energy source. The design and construction of an ocean energy plant is expensive. OTEC has many advantages apart from the energy. Similarly tidal energy systems have other benefits like linkage of places through the barriers in marshy areas. Multipurpose wave energy systems can be opted to reduce the cost and increase the system efficiency. Commercial exploitation of offshore wind energy is already leaping fast.

Any new technology development is expensive in the initial stages till large scale plants could be designed and developed successfully. It is very unfair to question the relative cost of power generation from such new and renewable energy systems when compared to conventional system for which worldwide technology development has been taken place decades ago at tremendous costs. Therefore, it is strongly recommended that R & D efforts in ocean energy development should be encouraged so that we could go in for more and more demonstration plants to facilitate reduction in the cost of such power plants. The commercialization of any new energy source is fraught with technical challenges, managerial dilemmas and political crisis.

Tapping power from non-conventional sources is relatively new area which needs more attention not only from academic and research institutions but also from Industrial sectors. A large number of industries around the World should participate to solve some of the technical problems related to the development of commercial power plants. It is expected that a large number of industries will come forward for supply of equipment, construction and erection of the power plants. The industrial participation will also help in the human resources development and development of new technologies.

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