OCEAN ENERGY TECHNOLOGY

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ABSTRACT

Ocean is a reservoir of energy. It is not only pollution free but also renewable. Development of suitable technologies for power generation from different forms of ocean energy is challenging. R&D works around the world has improved the hope for technical feasibility. Increase in the cost of fossil fuel is indirectly helping more focused research work on ocean power plants. It is hoped that more pilot plants will be installed at various ocean locations which may lead to commercial exploitation. This paper discusses the different forms of ocean energy, physics of energy conversion, and the technical challenges involved in the technology development.

1. INTRODUCTION

Ocean is one of the important pollution free and inexhaustible sources of energy. The research and development have been in progress throughout the world for development of technically feasible and economically viable methods to convert the various forms of ocean energy into usable form of energies. Already commercial production of tidal power was going on at few places in the world. Experiments with mini Ocean thermal energy conversion systems were also carried out by few countries. Few wave energy pilot plants were built and studied. 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 10 billion during 2050 (Fig.1), an addition of about 3.5 billion from the present day population.

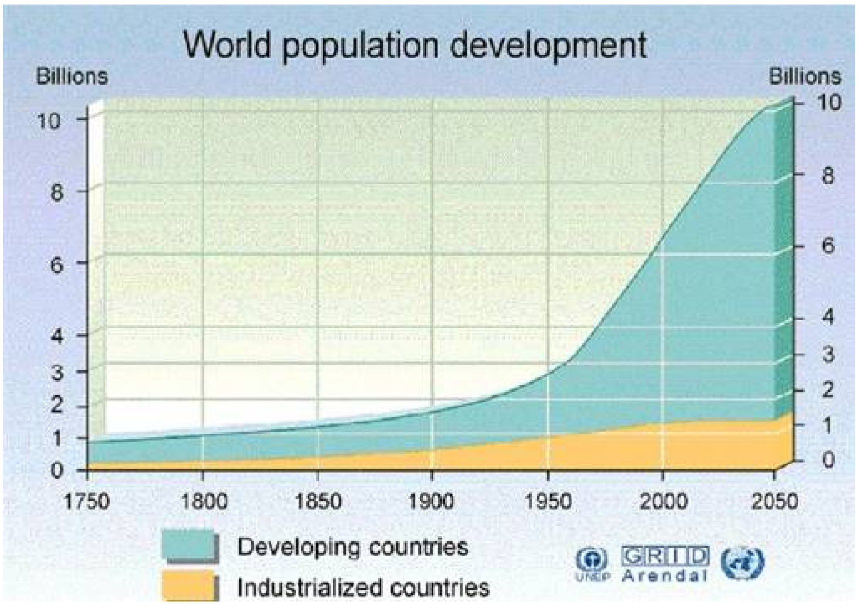

Fig.1 Predicted World population development

The world's energy demand also is expected to increase from 15000 GW to 27000 GW by 2050 (fig.2).

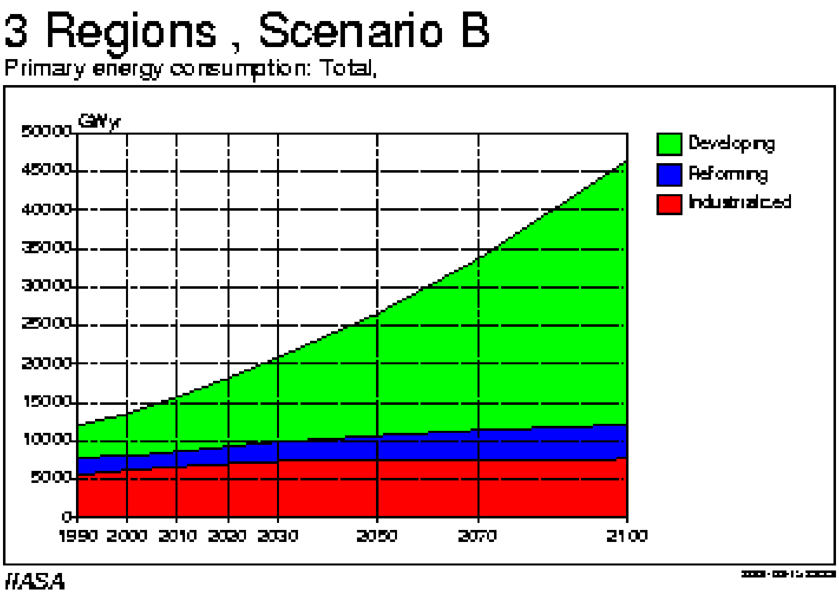

Fig.2 Predicted global primary energy demand

2. OCEAN AS AN ALTERNATE ENERGY SOURCE

Energy resources play an important role in the economic development of any country. During these 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} Watts of solar energy reaches the earth. The ocean, which covers about 71% of the earth's surface acts as a natural collector 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 and continuous throughout the year, pollution free and has minimum health hazards. For remote islands, ocean energy will be the most important form of alternative energy, since it comes from the immediate vicinity.

3. VARIOUS FORMS OF OCEAN ENERGY

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

1. Ocean thermal energy conversation (OTEC)
2. Wave Energy
3. Tidal Energy
4. Marine current
5. Offshore wind energy
6. Marine biomass conversion
7. Salinity gradient energy

Among the above, only the first three are likely to be technically and economically viable in the near future. The global distribution of ocean power technologies are as shown in Fig.3.

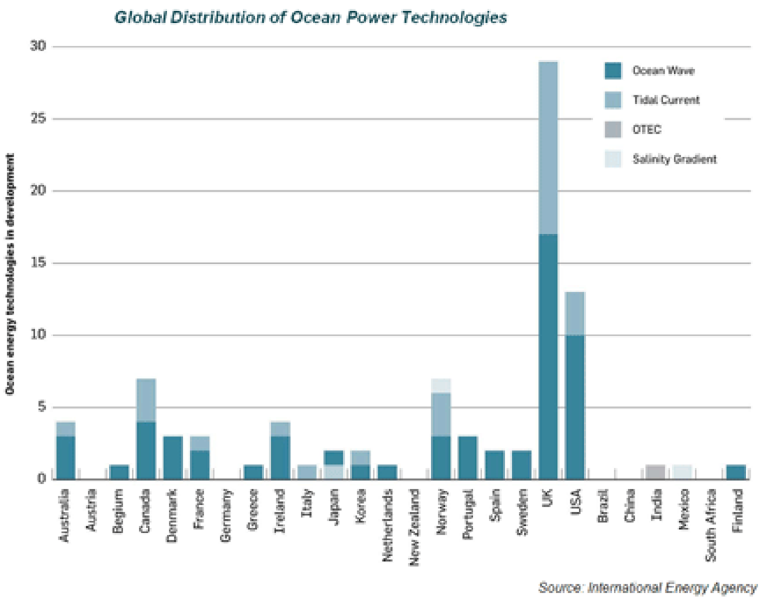

Fig.3 The global distribution of ocean power technologies

4. OCEAN ENERGY POTENTIAL AROUND THE WORLD AND IN INDIA

4.1 Estimates of Worldwide Ocean Energy Potential (Charlier, 1982)

The theoretical estimate of the various Ocean powers commonly found in the literature (in MW):

Ocean Thermal Energy Conversion (OTEC)	$40{,}000 \times 10^6$
Salinity gradients	1400×10^6
Marine bioconversion	10×10^6
Marine current	5×10^6
Wave energy	2.5×10^6
Tidal energy	3×10^6
Offshore winds	$>20 \times 10^6$

4.2 Basic Reason 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 plant are very expensive. During the late 70's large projects were undertaken in developed countries in developing the technology for the above ocean energy conversion system, because at that time, the oil prices were going up steeply. But in 80's the 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 international and Indian technological development relating to the above three forms of energy, and the prospects for commercialisation in the near future are discussed in this module.

5. OCEAN THERMAL ENERGY CONVERSION (OTEC)

5.1 Principles & Prospective Locations

OTEC utilizes the temperature difference between warm surface seawater of around 24^o C to 28^o C and the cold deep sea water of 5 to 7^o C (Fig.4), available at a depth of 800 to 1000 m. OTEC is attractive for countries with ocean located in between the Tropic of Cancer and the Tropic of Capricorn (Fig.5). The warm water overlies the colder water at depths of about 1000 m near 30^o S and 30^o 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^o S and 30^o N.

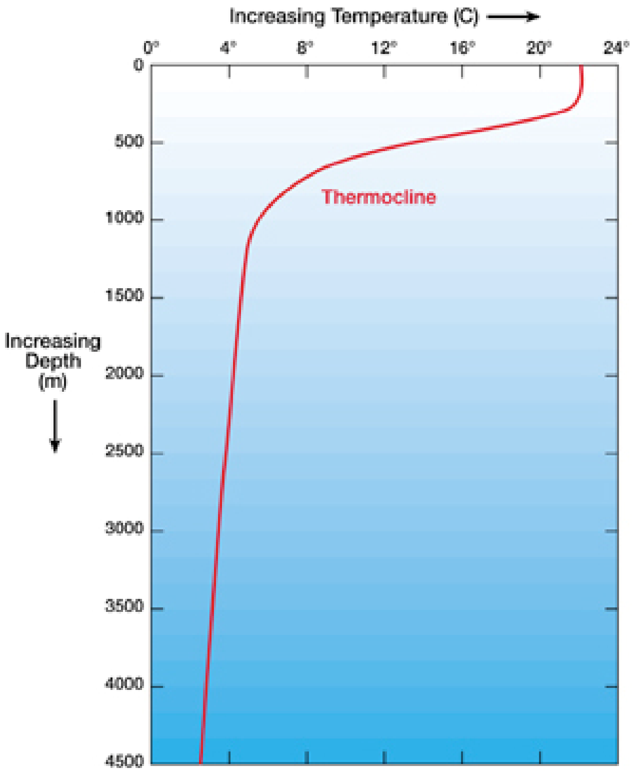

Fig.4 Thermocline in the ocean

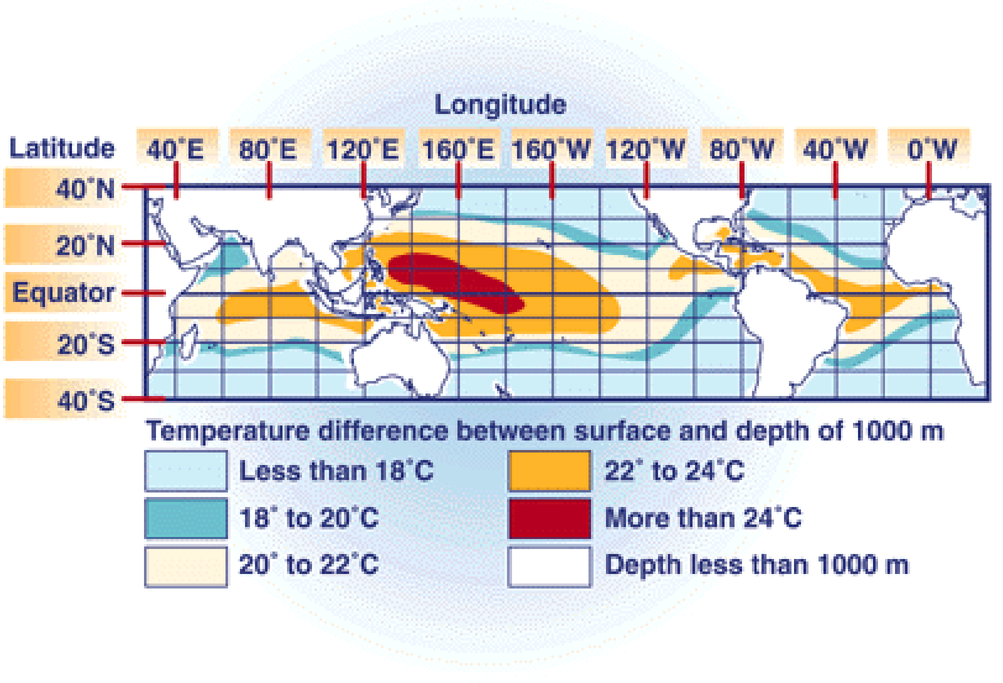

Fig.5 Temperature difference of seawater between surface and depth of 1000 m

5.2 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 generated vapour is utilised to drive a low pressure turbine connected with the generator. The exhaust steam is condensed using cold sea water (**Fig.6**).

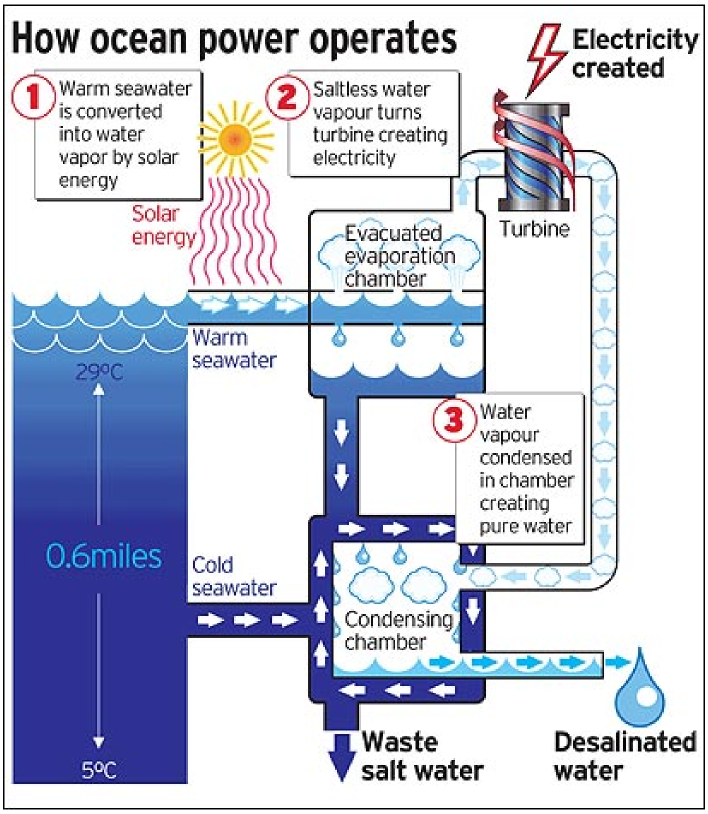

Fig.6 Open cycle OTEC system

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.7**).

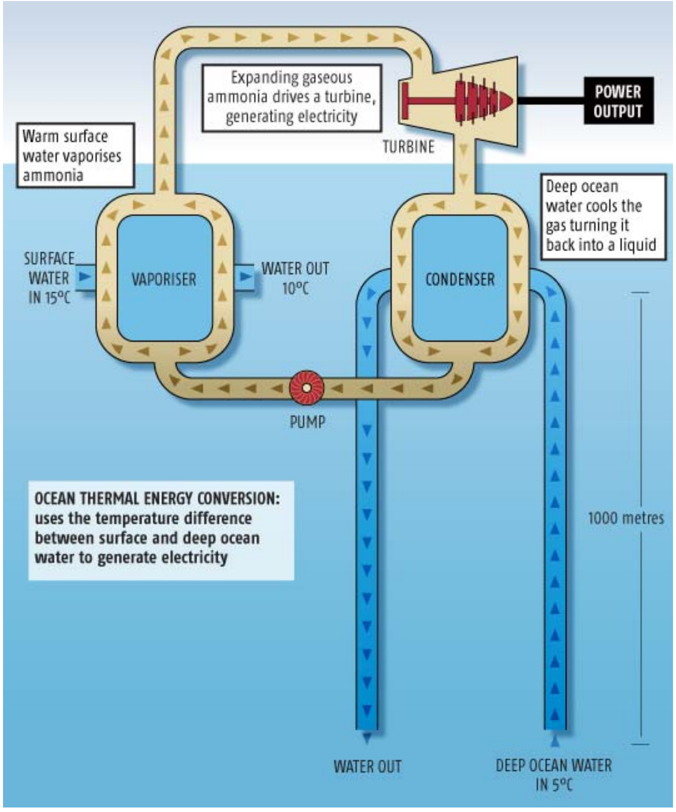

Fig.7 Closed cycle OTEC system

5.3 Comparison of the Two Cycles

The advantage of the open cycle is that warm sea water is flash evaporated and the need for having a surface heat-exchanger is eliminated. The other major advantage is that potable water is obtained when the exhaust steam from the turbine is condensed. But the major disadvantage is that the steam is generated at very low pressure (approximately 0.02 BAR) and the volume of steam to be handled is high leading to a very large diameter steam turbine. For example one MW OTEC plant requires a steam turbine of 12 m in diameter.

On the other hand, the closed cycle system requires expensive working fluids like Freon or Ammonia. But the major advantage of this system is that the fluid evaporates at around 25^{o}C and does not require vacuum pumps. The pressure at the turbine will be of the order of 4 to 5 bar resulting in compact turbines. For example for a 1 MW plant, the Ammonia turbine will have a diameter of about 0.6 m only.

5.4 Location of OTEC Systems

Depending upon the availability of deep sea near the coast, the OTEC system could be installed in three possible 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 (**Fig.8**). An underwater cable is needed for power transfer to the shore. Alternately, the generated power may be utilised 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.

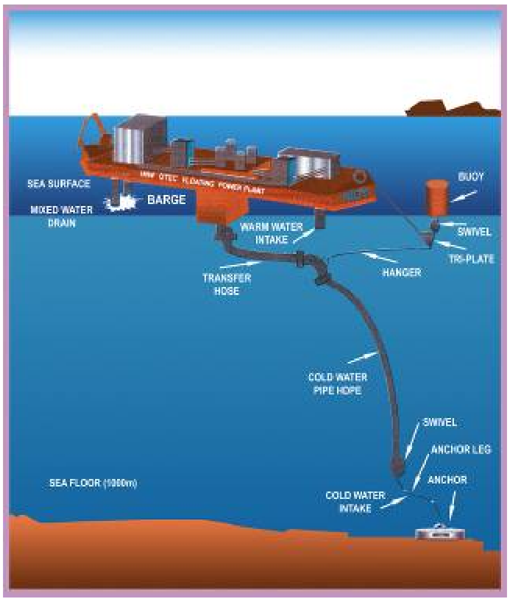

Fig.8 Floating OTEC plant

- 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 (Fig.9).

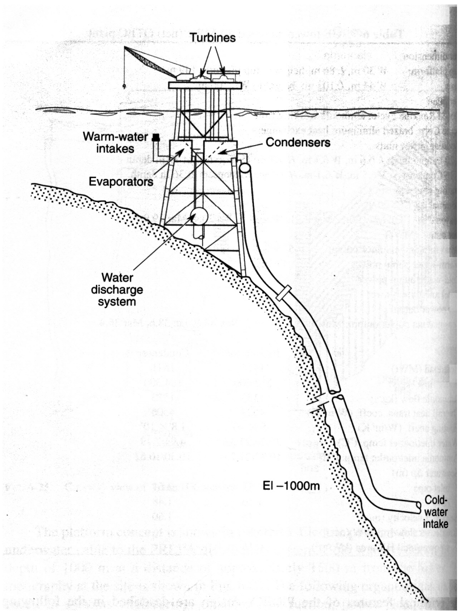

Fig.9 Shelf mounted OTEC plant

- If the deep water conditions are available within 2 to 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 to 1000 metres.

5.5 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 (Fig.10).

Fig.10 Different byproducts and benefits out of OTEC plant

- An open cycle OTEC system provides fresh water as by product. The closed cycle system can also be combined with a desalination plant to get fresh water.
- 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 and they can be shipped to the land for use.

5.6 Global Technology Development

The basic concept of OTEC was proved on a very small scale half a century back by George Claude. In USA, a 50kW demonstration plant named 'Mini OTEC' was deployed off Hawaii in August 1979 and operated for 4 months. Another demonstration plant, again off Hawaii known as OTEC-1, was intended to test heat exchangers for 1 MW energy was installed. An old ship was converted to a floating platform to house shell and tube type of heat exchangers. A 1.2 m dia 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 the working fluid. The experiments were completed in March 1981.

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 1970-71. Initially feasibility studies and conceptual design of large commercial 100 MW (four number of 25 MW modules) floating plants were undertaken. Subsequently, plans for construction of a 1.5 MW land based test plant have been proceeding. 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 meters. A large number of Universities, national government agencies and private companies are 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 is planned to go for 5 MW demonstration plants followed by 100 MW commercial plants.

5.7 OTEC Potential in India

India is geographically very well placed as far as the OTEC potential is concerned. Around 3000 kms of coast length along the south Indian coast from Bombay on the west, upto Vishakhapatnam on the east, a temperature difference of 20^{o}C throughout the year is available. Thus India has more than 0.3 million sq. kilometres of tropical waters in the exclusive economic zone, where sufficient temperature gradient exists throughout the year. Apart from this, there are attractive OTEC plant locations around the Lakshadweep, Andaman and Nicobar Islands.

5.8 OTEC Activity in India

The Tamilnadu Electricity Board has proposed a 20 MW OTEC plant off the Tamilnadu coast. They had carried out certain surveys with the assistance of National Institute of Oceanography (NIO), Goa and identified three possible locations along the Tamilnadu coast.

Since 1980, Indian Institute of Technology (IIT), Madras was investigating various aspects of OTEC and brought out a preliminary design report for 1 MW plant off Kulasekharapatnam in Tamilnadu. This preliminary study included a cycle choice in favour of closed cycle system with Ammonia as the working fluid.

The DNES (Departments of Non-Conventional Energy Sources) has established an OTEC project cell at IIT Madras since November 1981 to explore the feasibilities for a 1 MW OTEC plant off Lakshadweep Islands. Two sites were considered; One at the island of Kavaratti and the other at the Minicoy. On the eastern side of the islands, water depth of 1000 metres at a distance of 3 km from the island-coasts was expected. A land based plant with cold water pipe line running down the slope to a depth of 800 to 1000 metres was suggested. Both islands have huge shallow depth lagoons on the western side with hardly any nutrients in the sea water. The proposed OTEC plant will bring up highly nutrient deep sea water for aquaculture. Some estimates indicate that the revenue from aquaculture will be of the same order as the revenue from generation of electricity.

The National Hydrographic Office, Dehradun conducted a detailed hydrographic survey off these two sites. The results indicated that Kavaratti Island has a more uniform slope and hence preferred. Metallurgical and Engineering Consultants of India Ltd., (MECON) Ranchi has prepared and submitted a detailed project to Government of India in 1985 (Ref.9). MECON's estimate of cost of power generation was Rs.3.72 per kWh from this 1 MW OTEC plant, while the generation cost from the existing diesel generator system is at least Rs.7.00 per kWh.

The OTEC project group of IIT Madras has identified Andaman and Nicobar Islands as another suitable location for installation of OTEC plants. It was found that Sister and Cinque Islands can have cost competitive, land based OTEC plant but the power to be produced has to be transformed to South Andaman Islands by submarine cables. Chidiatapu of Southern Andaman and Rutland Island offers possibilities for shelf based OTEC plants. The cost of construction will be high because the tower for OTEC plants is to be constructed at a water depth of 100 m with submarine cable of 6 km long. But the power consumption point is near the plant.

A proposal was received from 'Sea Solar Power' of USA to install a 600 MW floating OTEC plant off Kulasekharapatnam, Tamilnadu. The power to be produced is to be soled to the government at the cost of US $ 0.059/kWh upto 2.9 x 10^{10} kWh; thereafter the cost will be only US $ 0.05kWh. This was the same site studied by the Tamilnadu Electricity Board, NIO, Goa and IIT Madras in 1982. A report (Ref.10) by IIT Madras and Tamilnadu Electricity Board was prepared in December 1989 recommending Government of India to seriously consider the proposal of M/s Sea Solar Power. This proposal is still under consideration by Government of India.

During 1995-96, Government of Tamilnadu has signed a MoU with Sea Solar Power, USA for likely implementation of a 100 MW (8 x 12.5 MW units) plant off Southern Tamilnadu coast. Sea Solar Power was planning to build and operate the plant and sell the power to the electricity board.

5.9 Commercialisation of OTEC

OTEC is capital intensive. Based on available estimates the capital cost for OTEC units of 100 to 400 MW range is from 2400 - 4000 US $ per kW. 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. OTEC systems are likely to solve, at least in part, the current and further requirements of electricity for countries located in OTEC favourable regions.

Until operational experience is obtained on larger size OTEC plants and economic performance can be verified through commercial demonstration of OTEC technology, investment uncertainty will exist. 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.

6. WAVE ENERGY

6.1 General

The ocean wave is an inexhaustible source of energy. About 1.5 percent 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 share 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. The wind energy, transferred to large sea surface is stored as mechanical energy in waves. The inertia of the waves provide this short time storage and also tends to smooth out part of the high variability of wind power.

The wave energy potential varies from place to place depending upon its geographic location (Fig.11). Even at a given place, the energy availability varies during the different parts of the day, for different months and from season to season.

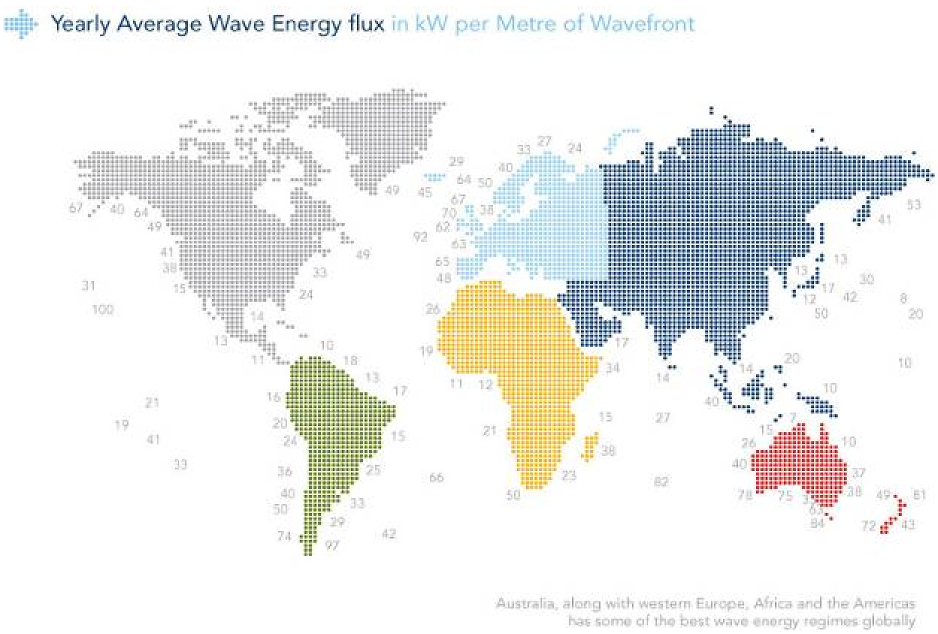

Fig.11 Wave Power Variation Around The World (Source: Google Web)

6.2 Estimation of Wave Energy Potential

The power available in the Ocean wave is expressed as

$P = 0.55\, H_s^2 T_z$ kW / m length of wave crest

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 sec 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 to 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 to 2.0 m with average wave period from 6 to 10 seconds and hence the annual average wave power is between 5 kW/m to 15 kW/m.

6.3 Types of Wave Energy Convertors

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

6.3.1 Buoys or Floats

Floating buoys have been developed which can 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 (Fig.12). The magnet is surrounded by a copper wire coil. As the magnet moves back and forth through the coil an electric current is automatically generated. One of the advantages of this approach is that the current is produced directly without the need of a generator.

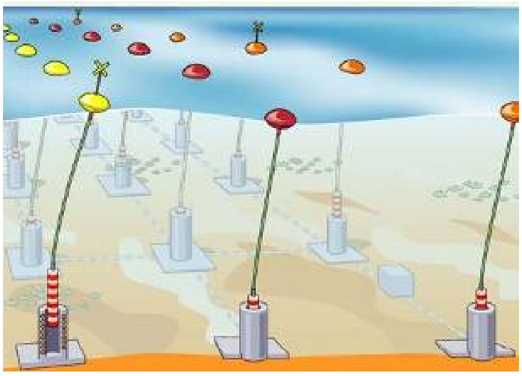

Fig. 12 Floating Buoy Type Wave Energy Converter (Source: Google Web)

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 (Fig.13) 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.

Fig. 13 Pelamis Wave Energy Converter (Source: Google Web)

6.3.2 Oscillating water columns

Another approach to generating energy 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.14).

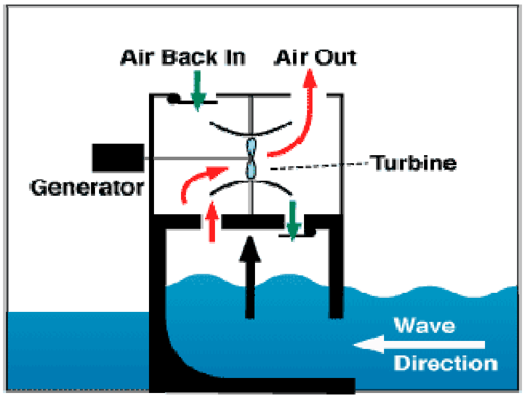

Fig. 14 Oscillating Water Column (OWC) Type Wave Energy Converter (Source: Google Web)

6.3.3 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 (Fig.15). 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.

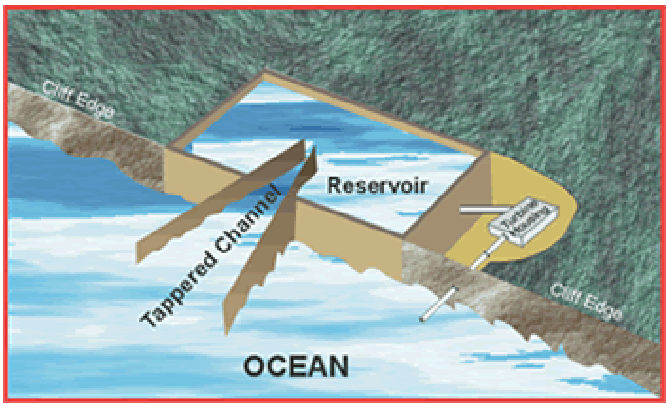

Fig. 15 Tapered Channel Wave Energy Converter (Source: Google Web)

6.4 Pros and Cons of Wave Energy Generation

6.4.1 Pros

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 devices are capable of producing 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 ocean and so the capacity for waves as a renewable energy source is enormous.

6.4.2 Cons

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 feet 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.

6.5 Global Technology Development

United Kingdom and Japan are the pioneers in the wave energy development, while Portugal, Ireland, Norway and the USA also have started serious R & D activities. Few hundreds of patents have been registered on different types of wave energy devices. The United Kingdom has spent about 4 million pounds on wave energy research activity till 1980.

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 this development became a joint effort between UK and Japan.

The OWC system consists of a chamber in the sea exposed to wave action through an entrance at the bottom or on the side. The air inside the chamber gets pressurised or expanded due to wave action. Air movement through a small opening from or into the chamber is utilised to drive an air turbine.

The OWC system with the air turbine was subjected to sea trial in the Sea of Japan in October 1979. An 80 m x 12 m barge with vertical openings, named 'Kaimei' with 9 sets of impulse air turbine and generators, each of 125 kW was used. Four valves were used in every turbine to rectify the pulsating air flow in the chamber to a uni-directional flow to the turbine. The average output of the system was not as high as predicted.

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 capacities 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 one year before it was knocked down by 20 m high cyclone waves during December 1988.

Another plant known as 'Tapchan' was built in Norway. This plant guides the incoming waves through a tapered channel allowing the waves to shoal into a reservoir, thus raising the water level above the sea level. This water is allowed to run through the conventional Kaplan turbine, utilising the water level difference between the reservoir and the sea.

An offshore device was built by Japan as a part of their breakwater in Sakata port. This caisson with a width of 22 m standing at a water depth of 18 m has a twin rotor Well's turbine with a 80 kW DC generator. The system was commissioned during 1990 and performance evaluation is in progress.

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 installed in 1990. The turbine has an induction generator of 75 kW. 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 (Falcao A.F.de O. et. Al. 1993) (Ref.15). 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 the following sites for the construction of pilot plants:

a) The island of Islay in the United Kingdom
b) The Old Head of Kinsale in Southern Ireland
c) The island of Pico in the Azores.

The European plant on Islay will demonstrate the 'designer gully' method of construction in which the water column structure is build in a man-made recess in an otherwise straight length of coastline. The plant in Pico will utilise a natural rock gully and will demonstrate a more advanced form of the construction. Works are in progress for the construction of a 500 kW wave power plant in Azores, Atlantic Ocean and one at Island of Islay.

Recently, Japan has considered a variety of wave energy converting systems:

a) Pendular type at Muroran Port of Hokkaido
b) Wave power generating system with a constant air pressure tank at Kujukuri beach
c) Pneumatic wave power conversion system with water valve rectifier in the breakwater of Haachi Fuel Station (Under construction from 1994)
d) Floating wave power device "Mighty Whale" to be installed at the offing of Gokasho Bay of Mie during 1997.

The progress of research and development in Japan was 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 economise the commercial wave power plants.

6.6 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 utilises that may arise by regulating the waves. A multi-purpose wave regulator system has been proposed by the Wave Energy Group, Indian Institute of Technology, Madras, with the following objectives:

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

6.7 Prototype Testing of a Wave Energy Caisson in India

Department of Ocean Development (DOD), Government of India, has supported the wave energy group of IIT Madras to investigate one such type of system for the last one decade. The initial objective was to identify a suitable wave power absorbing system and location for the installation of 150 kW capacity pilot plants (Fig.16). 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 m x 17 m in plan and 18 m high weighing about 3000 tons 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, directly connected to the electricity grid. The caisson is connected to the top of the breakwater of the harbour by a steel bridge (Fig.17). This system has been commissioned on October 1991 and performance monitoring was carried out.

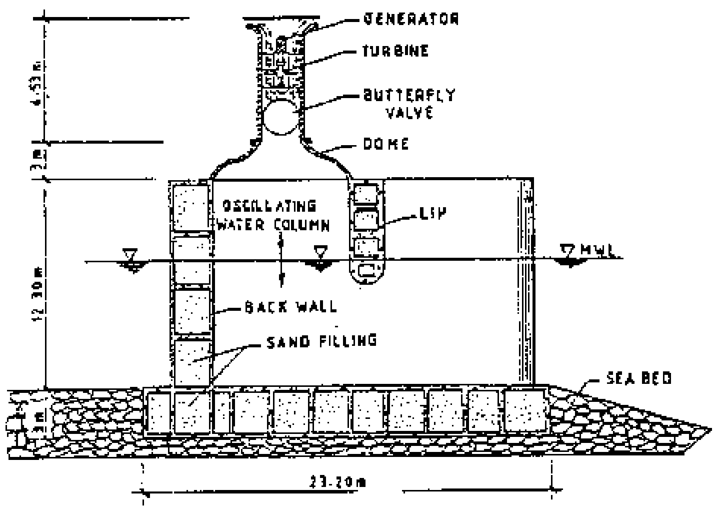

Fig. 16 The C/S View of the Indian Wave Power Plant

The 150 kW capacity wave power plant is located in Vizinjam, Kerala, India in the Arabian Sea (Fig.17).

Fig. 17 The Rear Side Views of the Indian Wave Power Pilot Plant

Instrumentation systems were provided to measure the incoming wave climate, wave induced pressures on the wall of the caisson structure, air velocity and pressures through the turbine, its speed, power and the energy pumped to the grid. The turbine was capable of self starting and has generated a peak power of 150 kW. The various parameters of the power module vary strongly with the incoming wave heights and periods. 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.

6.8 Further Indian Wave Energy Activities

Based on the experiences gained, the design and fabrication of a 55 kW horizontal axis power module for commercial application was completed. This 55kW turbine was tested using the pilot plant at Trivandrum. The performance monitoring of the system was carried out over an extended period.

Extensive experimental investigations to optimise the spacings between the caissons in array and wave forces were conducted. The structure configuration of the caisson is also modified for improved floating stability, berthing requirements and space for ballasting. Studies on improving the efficiency of power absorption and optimisation of the cost of construction were carried out. Physical model studies on different types of harbor configurations to improve the pneumatic efficiency and to reduce the wave loads were carried out. NIOT has carried out field test with various types of turbines and generators to find out the suitable one for commercial exploitation of wave power.

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 harbour near Quilon in Kerala state and 1.0 MW system for Musbay in Car Nicobar Islands

(Neelamani et al. 1995)(Ref.17). Further research and development is in progress to increase the conversion efficiency and reduce the cost of construction.

6.9 Commercialization of Wave Power Plant

Urgent need to avoid the emission of green house gases by firing hydrocarbons has been felt by the society. Abatement of the green house gas is an expensive task.

The recent wave power technological development in India and Japan shows that in near future the cost of production of wave power can be comparable to the conventional power production cost, if the other benefits of the breakwater type caissons are also suitably considered in the estimation of cost/benefit ratio. The cost of wave power is site specific. Fore example, it is estimated that the wave power production cost during 1995 for islands like Andaman Nicobar and Lakshadweep is about \$0.195/kWh (Neelamani et al.1995)(Ref.17) compared to \$ 0.20 per kWh generation costs from diesel generators.

It is expected that the cost of construction and implementation reduce with improved technology. The commercialisation of wave power expected to be a reality in the near future.

7. TIDAL ENERGY

The tide is the harmonic raising (Fig.18) and falling (Fig.19) of the ocean free water surface due to the attraction of moon and sun on the earth and the rotation of the earth.

Fig.18 A scene of high tide

Fig.19 A scene of low tide

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 (Example: Bay of Fundy in Canada). The tidal power plants are similar to hydroelectric power plants; the major difference is that the tides are periodic with a period of about 12 hours 25 minutes.

The water is captured in a reservoir during high tide (Fig.20) and is allowed to pass through turbines and generates power when the tide level falls in the open ocean side during ebbing (Fig.21).

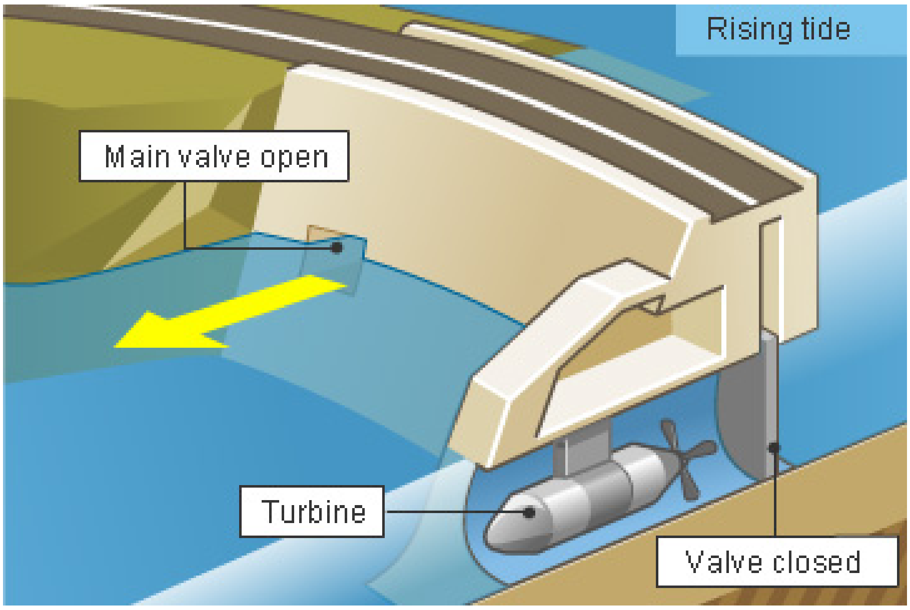

Fig.20 Water entering into the reservoir during rising tide

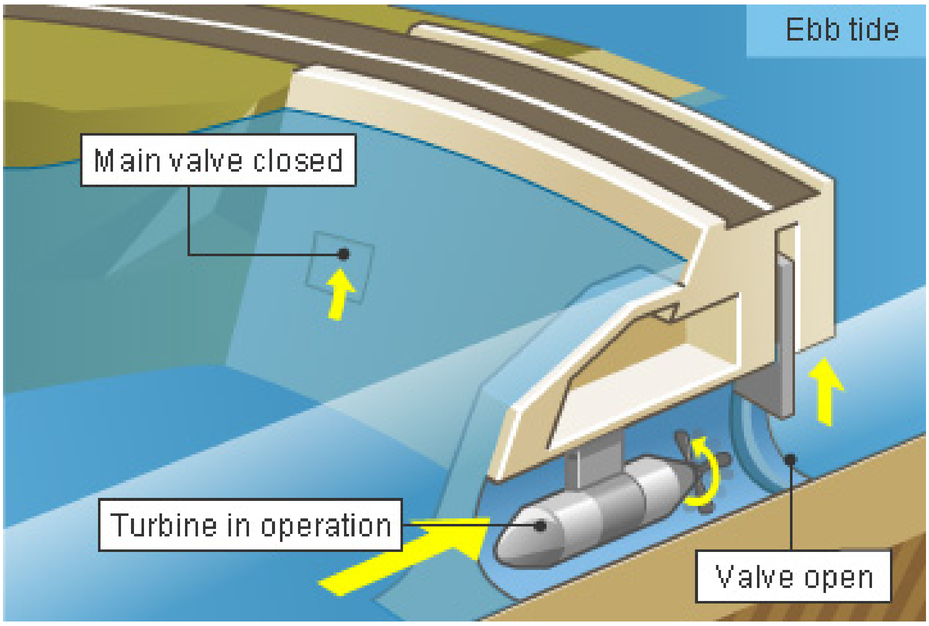

Fig.21 Power generation during ebb tide

7.1 Estimate of Tidal Energy

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

$E = 0.017 R^2 S$

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

7.2 Global Potential and Development

Tidal development has gone through long stages of development. There are 27 major tidal power plant sites identified throughout the world. The first one to go into commercial production is the Rance plant in France (Fig.22).

Fig.22 Rance Tidal Power Plant, France

About 350,000 m^3 of concrete and 16,000 m^3 of steel was used for the construction of the plant. The area exposed to the sea water is about 90,000 m^2. The construction work was proceeded inside a 10 hectare 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 plants are said to be currently in operation, producing electricity, with a total capacity of 7638kW. A 3.0 MW plant called Jain Xia tidal power was commissioned in China during 1982.

In Annapolis, Nova Scotia, Canada a tidal power plant of 20.0 MW capacities was commissioned during 1984. The mean tidal variation in this site is 5.1 m.

In spite of the fact that two tidal plants are in operation for more than 10 years, 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 serious considerations.

7.3 Tidal Power Potential in India

Three sites in India have been found 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, Mr.E.Wilson indicated a possibility of installing very large tidal power station in the Gulf of Cambay, and Kutch and smaller power stations in Sundarbans area. Installed capacities of about 7300 MW, 1000 MW 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.1925 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.

Realising 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 Government of India **(Ref.12).**

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 has 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.

7.4 Commercialisation of Tidal Power Plants

Already commercial level tidal power plants are in operation throughout the world. For example

1. La Rance, Brittany, France
2. Kislaya Guba, USSR
3. Annapolis, Nova Scotia, Canada
4. Jian Xia, 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 important points in favour of tidal power schemes are:

1. The tidal power is regular from year to year with less than 5% variation.
2. The tide is accurately predictable and hence the tidal power potential and average annual power.
3. The tidal power is inexhaustible and pollution free.
4. The life of plant is of the order of 75 to 100 years
5. The technology of power production is simple, similar to hydro-electric power stations.
6. 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 to 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 favourable. 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 further of tidal power remains a matter of economics and perhaps of politics as well.

8. POWER FROM OCEAN CURRENT

Building the barrage is an expensive process. There are many locations in the oceans, where the water current speed is more than 1 m/s for most of the time. The kinetic energy of the current can be used to run underwater turbines and generate power (Fig.23).

Fig.23 Power generation using Ocean current

9. OFFSHORE WIND ENERGY

Around the world, already hundreds of wind turbines are installed in the offshore waters. The wind energy potential is high in the sea when compared to land side. However, the cost of installation is high and the maintenance is also expensive in the marine environment.

Fig.24 Offshore wind mills

10. CONCLUSIONS

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. Wave energy systems with additional benefits are proposed and works are in progress to reduce the cost and increase the system efficiency. Offshore wind energy and commercial exploitation is 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 world wide technology development has been taken place decades ago at tremendous cost. 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 commercialisation 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 institution but also from Industrial sectors. A large number of industries around the world 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.

11. REFERENCES

1. Augusta Goldin. (1980). Ocean of Energy – Reservoir of Power of Further, Harcourt Brace Jovanovich Publication, New York
2. Basker, A.C. (1991). Tidal Power, Peter Peregrinus Ltd, London, UK.
3. Brin Andre. (1981). Energy and the Oceans, Westbury House. UK
4. Charlier, R.H.(1982). Tidal Energy, Van Norstrand Reinhold Co., New York.
5. Charlier, R.H. and Justus, J.R.(1993). Ocean Energies – Environmental, Economic and Technological Aspects of Alternative Power Sources, Elsevier, Amsterdam.
6. Constans.J. (1979). Marine Sources of Energy, Pergamon Press, New York,
7. Conference Proceedings:
   a. Fourth OTEC Conference, 1977
   b. Fifth OTEC Conference, 1978
   c. Sixth OTEC Conference, 1979
   d. Seventh Ocean Energy Conference, 1980
   e. Eighth Ocean Energy Conference, 1981
   f. Oceans 82, Oceans 83 and Oceans 84
   g. First and Second symposia on "Wave Energy Utilization", 1979 & 1982.
   h. Proceedings of International Symposium on Ocean Energy Development - for Overcoming The Energy and Environmental Crisis, OTEC, 26-27 August, 1993 Muroran, Hokkaidu, Japan,
   i. European Waves Energy Symposium, Edinburgh, Scotland, 21-24 July, 1993.
   j. Second European Wave Power Conference, Lisbon, Portugal, 9 – 10 November 1995.
8. David Ross. (1981). Energy from the Waves, Pergamon Press, New York
9. Energy, Vol5, June 1980,Special issue on OTEC, Pergamon Press, New York
10. Falcoa.A.F.de O., Whittaker.T.J.T. and Lewis A.W.(1993). Joule II
    Preliminary Action: European Pilot Plant Study. 1993 European Wave Energy Symposium, Edinburgh, Scotland, 21-24 July 1993, pp.247-257.
11. Neelamani, S., Koola, P.M., Ravindran, M. and Raju, V.S. (1995). Wave power Economics: Case Study for Two Different Sites in India. Second European Wave Power Conference, Lisbon, Portugal, 8 – 10 November 1995.
12. Ocean Energy recovery – The State of Art.(1992). Edited by Richard J. Seymour, American Society of Civil Engineers, New York.
13. Panchal C.C.B. (1986). OTEC Technology report of OTEC Project Cell, Ocean Engineering Centre, IIT, Madras, January 1986.
14. Ravindran,M. and Paul Mario Koola. (1991).Energy from Sea Waves – The Indian Wave Energy Programme, Current Science Journal, Volume 60, No.21, pp.676-680.
15. Report on 600 MW OTEC Plant off Tamilnadu Coast. Prepared by Ocean Energy Cell, IIT, Madras and TN Electricity Board, Madras. Submitted to Dept. of Non-conventional Energy Sources, Government of India, December 1989.
16. Sharma, H.R. (1987). Power from Sea Tides. Lecture notes on Summer School on utilisation of Ocean Energy; Organised by Ocean Engineering Centre, IIT, Madras.
17. Shaw, R.(1982). Wave Energy – A design Challenge; Ellis Horwood Limited, John Wiley & Sons, New York.