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Ocean energy : Ocean Thermal Energy Conservation (OTEC) as additional electricity source for Nigeria

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I wish to express my profound gratitude and most sincere appreciation to my sponsor, the National Maritime Authority of Nigeria. I wish to also thank Captain M S Mohammad for advising and encouraging me to further my studies at WMU.

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DEDICATION

This dissertation is dedicated to Allah (God), Who ‘ let free two bodies of flowing water: one palpable and sweet (rivers or ground water) and the other salt and bitter (oceans); yet has He made a barrier between them, a partition that is forbidden to be passed’ (Qur’an 25:53).

ABSTRACT

Oceans cover more than 70% of the total surface of the earth and are vast resources of energy. Ocean energy can be retrieved by using adequate ocean energy systems that work on either temperature gradients, salinity gradients, density gradients, the flow of ocean winds, currents, waves, or tidal energy, all of which are renewable. They are never exhausted. The further the ocean energy systems are tested the more prosperous ocean energy becomes. It is certainly the energy for the future, especially when man finishes all the reserves of fossil fuels. Nigeria being the leading African nation, endowed with resources and at a vantage location should set the pace in trying ocean thermal energy conversion (OTEC) to boost her energy needs now or in the near future.

CONTENTS **PAGES**

CHAPTER ONE

1. INTRODUCTION

1.1 Ocean energy

Electricity can be produced using many types of energy systems. The traditional systems are the nuclear, solar, wind, gas and hydro. In addition, electricity can be generated through a new technology that uses the ocean as the source of power necessary to drive turbines and all the sources are renewable. The new generating technologies for deriving electricity from the ocean include tidal, wave, ocean thermal energy conversion (OTEC), ocean currents, ocean winds, salinity gradients, density gradients, and biomass energy systems. Each of the energy systems has certain unique advantages. The choice of which system to use depends on a number of factors such as the need, reliability, environmental effects and economic viability. But for sure, ocean energy would be the cheapest energy for the future. Therefore, the oceans can be utilised as an alternative or additional source of electrical energy.

OTEC is an energy technology that transforms solar radiation into electricity by using the ocean's natural thermal gradients. Wave energy systems extract the kinetic energy of waves for conversion into power that rotate turbines. Tidal energy systems employ the power of tides that are produced by the gravitational pull of the sun and the moon on the oceans of the rotating earth to do work in turning turbines. Salinity energy systems uses the osmotic pressure difference set by the ocean and a river. Salinity energy can also be obtained by the process of reverse electrodialysis. Density gradient systems are similar to OTEC systems. Ocean wind systems uses the fierce wind blowing on the surface of the oceans to rotate wind generators. And biomass energy system, a non typical ocean energy system that uses the abundance of phytoplanktons & algae which are chemically converted to methane. Methane is used to fire thermal electricity stations.

Each of the energy systems requires the most favourable site for optimal performance. Not all sites and conditions are suitable. For example, OTEC energy systems would only operate in the tropics, specifically between latitudes 20 degrees North and 20 degrees South. Tidal energy systems are only possible at locations where the mean tidal range is at least 7 meters.

1.2 Nigeria

The Federal Republic of Nigeria is a West African country, bordering Gulf 0f Guinea, Niger Republic, Benin and Cameroon. Nigeria's geographical co-ordinates are 10°-00.0 N, 8°-00.0 E. The country's total land and water area is 923 770 square kilometers, its coast spans some 853 kilometers and has a maritime claims as follows: continental shelf – 200m, exclusive economic zone – 200nm and territorial sea – 30nm (CIA Publication, 1999, p.1).

Nigeria is a major exporter of petroleum and petroleum products. It is a member of Oil Producing and Exporting Countries (OPEC) and produces over two million barrels of oil per day. The Nigeria's capital intensive oil sector provides 30% of GDP, 95% of foreign exchange earnings and about 80% of budgetary revenues. Nigeria's total export value as at 1996 was 15 billion US dollars. Other natural resources that the country is endowed with include tin aluminium, columbite, iron ore, coal zinc, lead, limestone and natural gas. Nigeria has both heavy and light industries. Some of them are, crude oil, coal, tin, columbite, palm oil, peanuts, cotton, rubber, wood, hides & skin, textiles, cement and other construction materials, food products, footwear, chemicals, fertiliser, printing, ceramics, aluminium and steel. Agricultural production is also very significant (CIA Publication, 1999, p.5).

Nigeria is the most populous nation in Africa. Recent head count put the population at over 100 million. The major tribes/languages in the country are the Hausa, Fulani, Yoruba and the Igbo. English is the official language. The major religions in the country are Islam (50%), Christianity (40%) and traditional beliefs (10%).

Politically, Nigeria is divided into 36 administrative zones, called states and one Federal Capital Territory, Abuja (FIG. 2.1). The states are Abia, Adamawa, Akwa-Ibom, Anambra, Bauchi, Bayelsa, Benue, Borno, Cross River, Delta, Edo, Ekiti, Ebonyi, Enugu, Gombe, Imo, Jigawa, Kaduna, Kano, Katsina, Kebbi, Kogi, Kwara, Lagos, Nassarawa, Niger, Ogun, Ondo, Osun, Oyo, Plateau, Rivers, Sokoto, Taraba, Yobe and Zamfara. Each state is further divided into many local administrative areas in order to bring people closer to the government.

1.3 Electricity production

Electricity is being produced in Nigeria by the National Electric Power Authority (NEPA) through two traditional means. These are the hydro and thermal electricity stations. The quality and quantity of power generated has been poor due to problems ranging from insufficiency of power stations, obsolete nature of the plants, electricity generation limitations to natural constraints associated with the conventional sources of electric energy, especially the hydro. As the result, NEPA has not been able to satisfy both domestic and industrial needs. NEPA's erratic power supply has not only affected the socio-economic activities of domestic users but also caused losses to industries. In some quarters, NEPA has been relegated to standby position as far as steady supply of electricity is concerned. As such, electricity generators are being widely used.

In order to salvage NEPA's problems, Nigerian government had set up several committees to study the situation with the view to diagnosing the scope and nature of NEPA's problems. Some of the committees are the Onosode Presidential Commission on parastatals, the Arthur Anderson Group, the British Electricity International and the World Bank. Informed individuals have also contributed in finding solution to NEPA's problems. Some of the memoranda suggested that NEPA should be partially privatised. Some suggested for additional hydro stations while some opted for alternative energy systems.

Alternative energy systems in Nigeria means all other feasible energy systems apart from gas and thermal plants. These include ocean energy systems, of which OTEC seems the most feasible.

1.4 Objectives of the dissertation

The objectives of writing this dissertation are:

- To propose OTEC as an additional or alternative energy source for Nigeria.
- To show that oceans are large resources of the much needed electrical energy.
- To examine the various methods or means of retrieving the ever abundant ocean energy.
- To indicate environmental effects of the several types of ocean energy systems.
- And to point out that ocean energy holds a great future especially when the prices of fossil fuels go up considerably, or when the fossil fuel deposits are exhausted.

1.5 Research method

The research methods followed in preparing this dissertation are:

- Library research.
- Visit to electricity generation plants.
- Collecting information from Professors, and
- Collecting information from the Internet.

1.6 Difficulties encountered

I wish to state that I had not suffered peculiar difficulties in conducting research for this dissertation. There are a lot of materials on the Internet and the World Maritime University library that I have used extensively. My only handicap is that I have not been in physical contact with any of the ocean energy systems. Therefore, all I have written with regard to ocean energy systems were not based on any practical experience.

The only hard task I had to face was typing the hand written scripts. I had to pick every letter of the thousands of the words in this dissertation as I had no prior experience in using a computer or a typewriter. Back at home we rely on professional typists or secretaries. However, typing this dissertation was a welcomed physical exercise.

CHAPTER TWO

TRADITIONAL SOURCES OF ELECTRICITY PRODUCTION IN NIGERIA

Electricity is being produced in Nigeria by the National Electric Power Authority of Nigeria (NEPA) through eight generating power stations. The stations are located strategically nation-wide. Three of the stations are hydro while the rest are thermal (Understanding NEPA, 1998). The three hydro-electricity plants are:

- Kainji
- Jebba
- Shiroro

The five thermal plants are:

- Sapele
- Delta
- Afam
- Ijora
- Egbin

2.1 HYDRO-ELECTRIC STATIONS

Here is the brief history and the generating capacity of the hydro-electric stations available in the country:

Kainji hydro-electric station

The increasing demand of electricity for industries and the expansion of small towns into big cities compelled the federal government to approve the construction of Kainji station in 1962. The station uses the water resources along river Niger in Niger state. The station was commissioned in 1969.

The station begun operation with only four generating units. Each unit has a power of 80 megawatts (MW). In 1970 two additional units of 100MW capacity were installed. Again, in 1978 two 120MW generating units were installed. Therefore, the total installed capacity of the station is now 760MW(Understanding NEPA).

Jebba hydro-electric station

The Jebba station was constructed in 1985 following more demand in electric energy. It was also built along river Niger. The station has six turbines (generating units) of about 90MW each (Jebba Power station, 1998). The total capacity of the station is 578.4MW.

Shiroro hydro-electric station

The Shiroro station is also owned by NEPA. It is the newest hydroelectric station commissioned. It started operation in 1990. Unlike the other two older stations, Shiroro station is not on river Niger. It has been sited on Shiroro Gorge on river Kaduna. The optimal power generated by this station is 600MW.

The Shiroro station is the only one to have supplementary National Control Centre (NCC). At this centre the generated electricity is build up into the national grid. The other two stations have their control centre at Oshogbo, which is far away from the stations.

2.2 THE THERMAL ELECTRIC STATIONS

Nigeria's demand for electricity is high and has been increasing rapidly. This explains why the country should have diverse sources of generating electricity. The sources should be as many as can be obtained naturally. Nigeria is blessed with natural gas, which can be used to generate electricity. For this reason thermal power stations were built and maintained. The stations use liquefied petroleum gas or natural gas. These stations serve as an additional source of electricity. The thermal power stations in Nigeria are briefly described as follows:

Afam thermal-electric station

The Afam thermal-electric station is situated at Port Harcourt in Rivers state. It was built in 1963.The citation of the station was due to the fact that natural gas is cheaply and abundantly available in the state. Natural gas is the main important to electricity plants that are thermal.

The initial power generated when the station was commissioned was 210MW. But because of increasing demand of electricity the station had to be upgraded by expanding the power station. As the result the installed capacity was increased from 210MW to 699MW. The input of the station to national grid is about 10% of the total national demand.

Lagos thermal-electric station

The Lagos station is sited at Egbin in Lagos state. It was commissioned in 1986. It is sophisticated and the biggest in West African sub region. The dire need for additional power, especially by new industries around the state necessitated the conception and construction was completed with the contribution of Mitsubishi of Japan, Monaco of Canada and some companies from United Kingdom. The generating capacity of the station is 1320MW. The power comes from six steam electric units. Each has a normal rating of 220MW.

Delta thermal-electric station

The Delta station is located at Ughelli in Delta state. The station was built in phases (I-IV) between 1966 and 1991. The final phase of the construction was done by General Electric of the United States of America and Marubeni of Japan. The station was later upgraded to meet the ever-increasing electricity demand around the region that housed the Aladja Steel Complex. Warri refinery and other heavy industries.

The power generation at the plant is 918MW. This figure amounted to the sum of power generated by all the phases (I-IV).

Sapele thermal-electric station

Sapele thermal station is located at Ogorode-sapele in Delta state. It is the second power station that was built in the state in order to satisfy increasing customers. The construction work was completed within a span of four years. The work was supervised by a Canadian company-Shawmant Limited. In 1984 the station was upgraded to produce more power.

The first section of the power station consists of six steam turbines, each capable of producing 120MW. The second section has four turbines with a combined power of 300MW. In total the Sapele station has a capacity of 1020MW, as at 1985.

The fuel gas utilise by the thermal station is being supplied by Nigerian Gas Company at Ogorode.

Ijora thermal-electric station

This station is sited at Ijora in the coastal city of Lagos. It is the first power station in the country. It has been in operation since early 1920s. The phase two of the station was built in 1965. The station has steam turbines and coal fired boilers (Understanding NEPA, 1998).

2.3 DISTRIBUTION OF ELECTRICITY AND ELECTRICITY GENERATION PROBLEMS IN NIGERIA

The sum of the electric power generated by each of the eight power stations is distributed through the National Control Centre (NCC) at Oshogbo in Osun state. The centre distributes electricity throughout the 36 states (and the capital, Abuja) of the country and even outside. The national grid extends up to Niamey and Gazaoua in Niger Republic. There are proposals to connect more cities in Niger Republic. The Republic of Benin is also soon to benefit from the electricity that NEPA generates and distributes.

In order to meet the demand of electricity by consumers both at home and abroad, NEPA must step-up electricity production and overcome natural and man-made obstacles. One of the ways of boosting the production of electricity is to explore and exploit another source such as the ocean.

Distribution of electricity

Distribution of electricity has been mainly through 330 and 132KV lines. As at 1997 the length of the lines added up to 11000km. There are plans to extend the transmission lines. Refer to FIG. 2.1 for the map of Nigeria showing national grid development plan up to the year 2005(source: NEPA). The map also shows the 36 states of Nigeria and the Federal Capital Territory, Abuja.

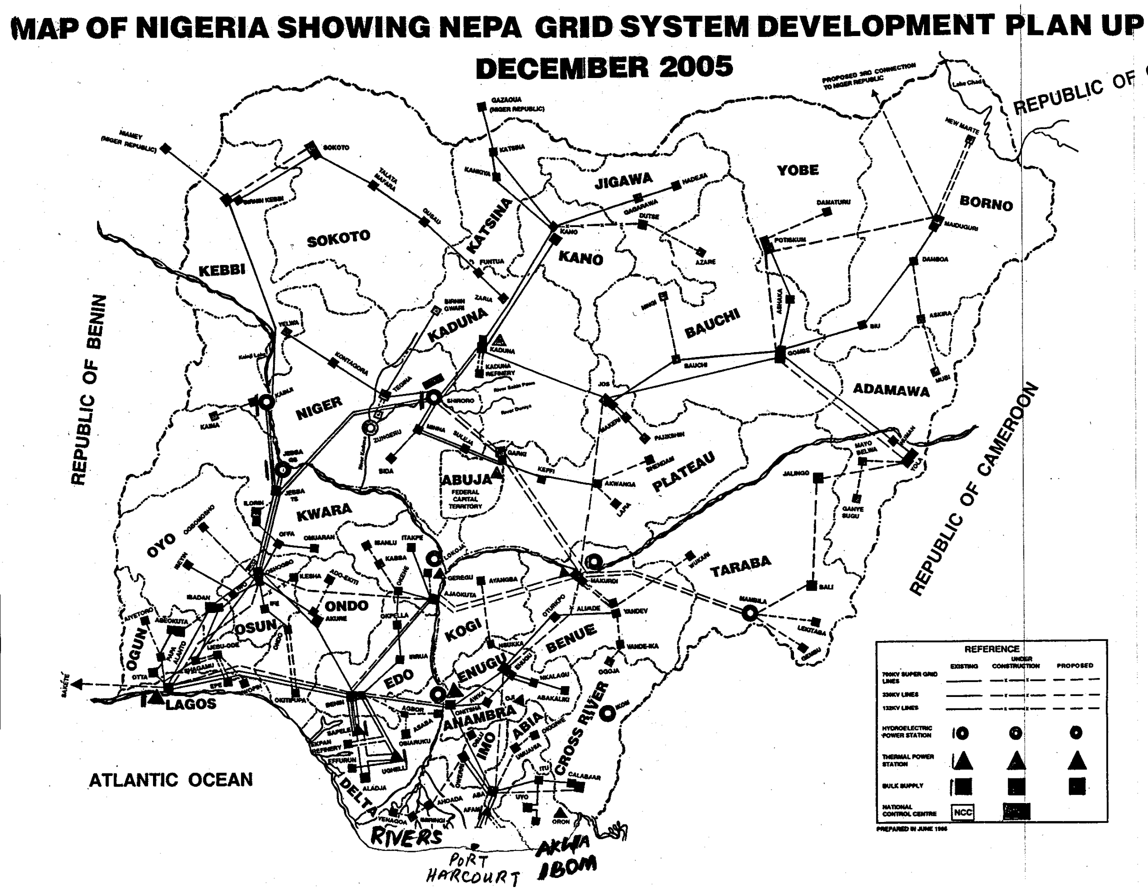


FIG. 2.1. Map of Nigeria showing NEPA grid system development plan up to December, 2005. The map also shows the 36 states of the country plus the Federal Capital Territory, Abuja.

Electricity generation problems

Electricity has been generated in Nigeria from hydro and thermal stations. The electricity that the plants are supposed to generate far exceeds the national peak demand. But even the peak demand has never been obtainable due to some constraints. And lack of sufficient number of electricity plants. Hence the reason why the quality and quantity of power generated has been poor. The other major reasons for the poor supply of electricity according to a NEPA publication, Load Shedding: Issues & Options are:

- Power generation limitation
- Over –aged or obsolete plants
- Increasing demand of electricity
- Decrease in investment into the industry

The three hydro-plants in Nigeria depend solely on the inflow of water into reservoirs or lakes, which in turn depends on annual rainfall. Therefore, production of electricity becomes low as the annual rainfall decreases. Decrease in annual rainfall seems to be the trend in Nigeria due to drastic weather reversals and, perhaps global warming. These are natural constraints to power generation in Nigeria.

Both the thermal and hydro plants in the country are over 10 or 20 years old. And are really in a state of disrepair. Some of the generating units and their auxiliaries have become obsolete and spares unavailable because they have outlived their operational lives. In fact they are supposed to be scrapped for new ones.

The demand for electric power has been on the increase since independence in 1960 due to increase in population, urbanisation and industrialisation. Modernisation is also another factor. People have begun to employ the use of electric-machines to take over works that were done manually, for example, washing, milling, grinding, etc. Lighting has also been on the increase as more villages abandon the use of candles and hurricane lamps in favour of electric bulbs.

There has also been general decrease of investment into the power industries. This explains why some of the thermal plants have been shut down. The ones out of service include Delta, Afam, Sapele and Egbin thermal stations (Understanding NEPA, 1998).

The total number of electricity plants seems to be inadequate considering the vast nature of Nigeria. Eight ailing power stations are definitely not sufficient for a country with a population of over a hundred million. In view of this, more power stations need to be built.

One of the ways of overcoming the problems of power generation in Nigeria is among other things exploiting another source of electricity such as the ocean.

CHAPTER THREE

THE NEED FOR ADDITIONAL SOURCE OF ELECTRICITY FROM THE OCEAN

The traditional sources of electricity in Nigeria have been gas and hydro plants. Both of which have natural and man-made limitations. For example, water flow is seasonal and depends entirely on weather conditions. Gas supply may not be forever due to depletion of gas reserves, industrial actions and machinery break- downs. Hence the dismal state of electricity supply in the country. It is therefore necessary that we explore other sources of power generation, transmission and distribution.

In the area of generation of electricity Nigeria has a total dependence on only thermal and hydro power stations. But other sources of electricity generation can also be exploited such as geothermal, wind, solar, biogas, nuclear and ocean energy.

3.1 ENERGY RESOURCES IN NIGERIA

Nigeria need not rely on just two sources of energy considering the energy resources that the country has been naturally endowed with. Other factors worth considering is the vast nature of the country, its teaming population, heavy and light industries and the necessity if having steady and uninterrupted supply of electricity on a twenty four-hour basis.

Solar Energy

Nigeria's earth surface receives solar radiation of about 5.5 Kilowatt-hour per square metre per day. Therefore, solar energy as a source of electricity for the country, no doubt, holds great potentials.

Wind Energy

Recent data indicate that the wind speed in the country exceeds the cut in wind of 2.2 metres per second at 25- metre diameter height for more than 80% of the wind stations in Nigeria. Experiments have shown that about 97MW per year of electricity was produced by a wind- tube of 25-metre diameter with 30% efficiency.

Ocean Energy

Nigeria is a tropical country that falls within an area where ocean-energy system such as OTEC (ocean thermal energy conversion) can be built. Within the country's territorial sea there is a substantial difference in the temperatures of warm surface water and cold deep water. The temperature difference has been observed to be between 22 and 24°C (National Renewable Energy Laboratory).

Other sources of energy from the ocean are for example, waves, tides and salinity gradients. All of them have practically been harnessed to produce electrical energy in places like Hawaii, France and USA, either as commercial or pilot projects.

Nuclear and Geothermal Energy

These are good sources of energy. Their potentials are yet to be fully ascertained in Nigeria. There are no plans to exploit these sources.

Hydro-electric Energy

Nigeria is blessed with rivers that are big enough for the production of hydro-electricity. At present there are three hydro-stations and there are also plans to build more. However, because of certain disadvantages of hydro systems there has been the need to look at other sources. The total installed capacity of the three hydro-electric stations in the country stands at about 2000MW.

Liquefied Petroleum Gas (LPG)

The production capacity of LPG – a source of energy is 306,000 metric tons per annum. This figure is big. It has even exceeds the local demand of about 120,000 metric tons. The mount is expected to double by the year 2000. It is used for cooking and as fuel for the thermal stations.

Natural Gas

This gas which is predominantly methane is abundant in the country. It is found in connection with crude oil and in some places not. It has been estimated that the reserve amounted to over three trillion standard cubic meters. Large amount of methane is also produced in the country during crude oil production. Although 75% is flared while the rest is either re-injected or treated as industrial gas and sold to industries mainly for electricity generation and other heavy industries in Nigeria.

Oil Products

Another source of energy in Nigeria is kerosene. It is one of the bi-product of petroleum refining. It is widely used in the country for cooking and occasionally for heating.

Coal

The coal reserve in the country amounts to over 2.75 billion metric tons. Coal is not very much used in the country. No thermal plant uses coal. It has mainly been exported to foreign markets.

Firewood

Firewood is a source of energy for cooking in Nigeria, especially in the rural areas. Out of the total land area of about 960,000 square kilometers, 40% of the land is forest. It has been estimated that between 51& 88 million cubic meters of wood is consumed annually, out of which 80% is consumed as firewood.

In view of the foregoing, Nigeria is endowed with variety of energy sources. Some are being exploited while some are not. It can also be said that some of the sources are renewable like the hydropower or ocean-power while thermal power and oil for example, are non-renewable. The modern way of generating electricity is the use of a renewable source that is available all the year round and that has zero or minimum impact on the environment. That is the kind of energy source most desirable for Nigeria, now and in the future. For this reason ocean is suggested as additional energy source for the country.

3.2 OCEAN ENERGY SYSTEMS

Ocean is another source of energy. There is energy in the ocean that can be harnessed for the production of electricity. The ocean energy can be tapped in different ways and most importantly it is renewable. The energy originates either from the sun, which is stored as heat energy in the ocean, or it is transferred from the atmosphere to the ocean in the form of waves. The gravitational pull of the sun and the moon on the water of the ocean basin yields tides which stores energy known as tidal energy (Pernetta J, 1995, p.110).

As at now there are only three well developed technologies for generating electricity from the ocean. These are the tidal energy systems, wave energy systems and ocean thermal energy conversion (OTEC). These systems will be treated in detail in this chapter. Electricity can also be generated from the use ocean currents, ocean winds and salinity gradients. The energy systems built on these principles would briefly be discussed in a separate chapter.

3.2.1 OCEAN THERMAL ENERGY CONVERSION (OTEC)

This is one of the attempts to produce cheap or abundant energy that is also renewable. Ocean Thermal Energy Conversion (OTEC) is a solar energy system. The ocean acts as a heat reservoir in the sense that it collects sunlight and keeps it in the form of heat energy. The principle of OTEC is to convert the heat from the sun (thermodynamically) into electricity using the OTEC system. The OTEC system generates electricity wherever there is temperature differential; for example, the temperature difference between surface and bottom water of the ocean. This is similar to the way in which electricity is generated by a conventional power station, say a thermal station that burns natural gas (or oil). In thermal stations, internal combustion provides the heat to generate steam which is then condensed back to water by cooling. This creates temperature difference required to turn a turbo-generator to produce electricity. In OTEC system the heat is provided by the temperature gradient of the ocean itself (Ford et al., 1987, p.61).

In the tropics there is a substantial temperature difference between the top and bottom parts of the ocean. The warm surface temperature is between 20° C and 25° C while the bottom temperature is between 4° C and 5° C (at the depth of, say 1000 meters). This is the basic requirement for the operation of OTEC system. The temperature difference though small is just enough to provide steady source of electricity. The ocean temperature difference does not vary significantly between day and night (Wick et al., 1981, p83).

OTEC Electricity System

Today there are three types of OTEC systems. These are the:

- Closed-cycle
- Open-cycle
- Hybrid-cycle

Closed-cycle OTEC system

In the closed-cycle system, heat transferred from the warm surface sea-water causes a working fluid (such as ammonia, which has a low boiling point at atmospheric pressure) to turn to its vapour (vapourisation). The expanding vapour drives a turbo-generator to produce electricity. Cold sea-water passing through a condenser containing the vaporized working fluid turns the vapour back to liquid which is then recycled through the system (DBET- Hawaii State Energy Office, 1995, p.1).

This system totally rely on heat transfer between sea-water and a working fluid such as ammonia or other suitable working fluid like propane or freon. But ammonia has been considered by most investigators as the best economic choice. In closed- cycle systems, heat exchangers called evaporators and condensers are the main component because large exchange surfaces are needed to convey huge amounts of heat at low temperature differences being exploited. In order to cut costs on the sizes of the heat exchangers required, the use of fluted metallic surfaces is being investigated by experts. Another way of improving heat transfer is more research on the working fluid.

During the operation of closed-cycle OTEC systems a layer of slime referred to as biofouling usually accumulates on the sea water side of the heat exchangers. This slime is initially composed of micro-organisms, at which stage the boifouling is called microfouling. Gradually, if the slime is not removed, larger organisms will become attached. Finally, the heat exchanger will keep mineral deposits and start to corrode away. Therefore, fouling and scaling must be frequently removed in order to prevent corrosion and maintain the efficiency of the heat exchangers.

Biofouling can be prevented or slowed down by the use of biocides such as chlorine. Mechanical cleaning is considered very helpful in removing scales off heat exchangers. The common mechanical devices used in cleaning are the man-brush and Amertap sponge-rubber ball. Similar but important cleaning techniques are the abrasive slurries and water jets (Wick et al., 1981 p.88).

Development of biofouling on heat exchangers depends on the location of the OTEC system. For example, biofouling forms rapidly on most coastal locations and forms slowly in open ocean-waters. Therefore, wherever biofouling becomes a menace it has to be cleared regularly, several times a month.

Another serious problem to heat exchangers is corrosion. Heat exchangers made of titanium rarely corrode, but they are very expensive. For this reason, aluminum that is cheaper is suggested. Other metals (or alloys) can be used provided they withstand erosion, pitting, corrosion and tear and wear as the result of mechanical cleaning.

Open-cycle OTEC system

Open-cycle (also called Claude-cycle) OTEC system uses warm surface water itself as the working fluid for the system. The water vaporizes in a partial vacuum at surface water temperatures. The expanding water vapor drives a low-pressure turbine attached to a generator that produces electricity. The vapor that has lost its salt and is almost pure fresh water, is condensed back into a liquid by exposure to cold temperatures from deep ocean water. If the condenser keeps the vapor from direct contact with sea water, the condensed water can be used for drinking, irrigation or aquaculture. A ‘direct contact’ condenser produces more electricity, but the vapor is mixed with cold sea water and the discharged water is salty. Therefore, that mixture is returned to ocean. The process is repeated with a continuous supply of warm surface water (DBET- Hawaii State Energy Office, 1995, p.1).

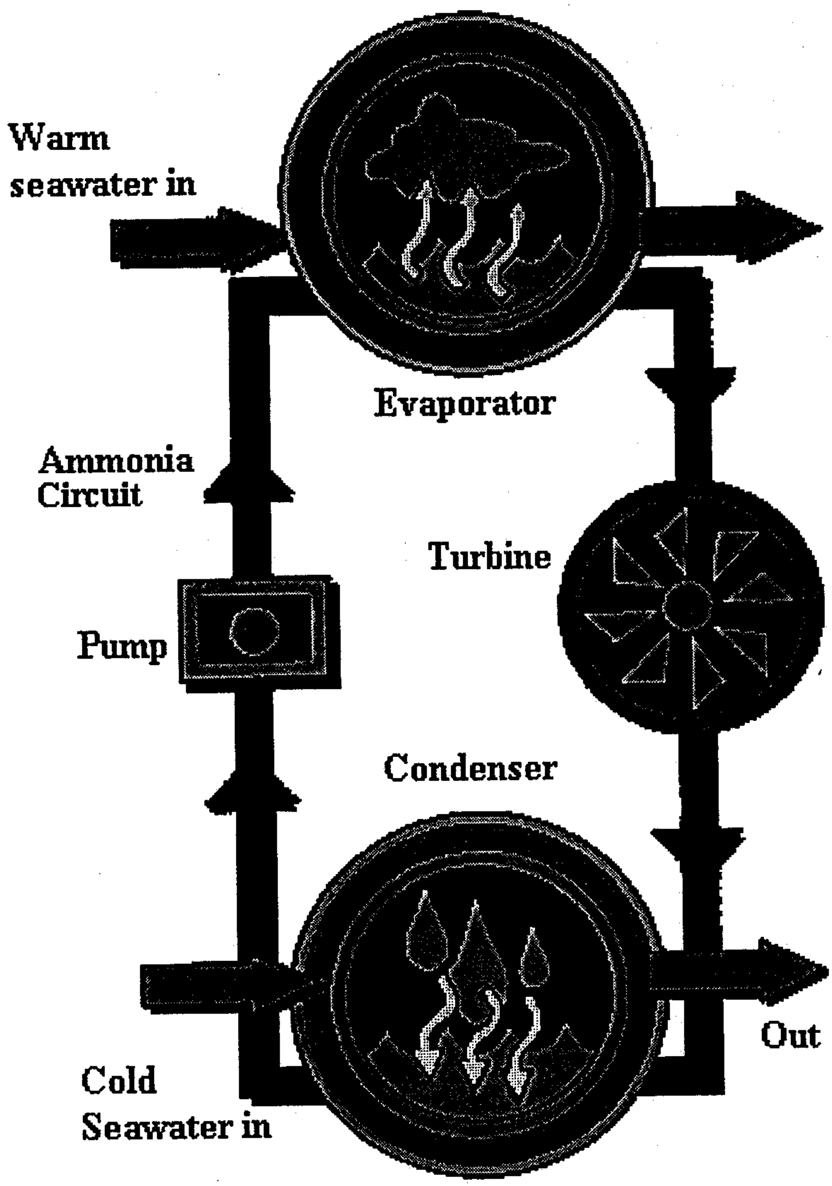
Open-cycle OTEC systems requires the use of extremely large turbines (comparable to wind turbines) for it to produce energy using steam at low pressure. In addition, degasifiers are required to remove gases dissolved in the sea water. Biofouling is not a serious problem to open-cycle systems. This is unlike the closed-cycle systems.

The cost of turbine used in open-cycle is by far greater than in closed-cycle systems. This is by virtue of its size.

Hybrid systems, which are still in the theoretical design stages, use parts of both open and closed-cycled systems to optimize production of electricity and fresh water(DBET- Hawaii State Energy Office, 1995, p.1).

The following FIGs show the diagrammatic representation of the open, closed and hybrid OTEC systems.

Principle of Closed-cycle OTEC



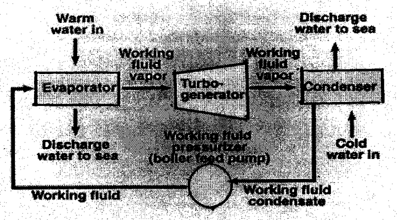
Warm surface seawater boils a pressurized working fluid such as ammonia at an evaporator. a turbine uses the vapour power to generate electricity. Cold deep sea water changes the vapour back into liquid at a condenser.

FIG. 3.1 Closed cycle OTEC

Electricity Production

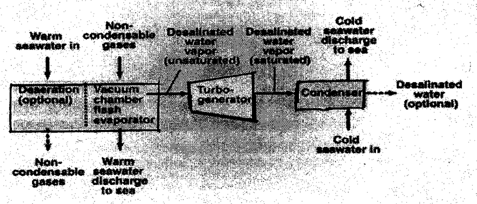
Two basic OTEC system designs have been demonstrated to generate electricity: closed cycle and open cycle.

Closed-Cycle OTEC System



In the closed-cycle OTEC system, warm seawater vaporizes a working fluid, such as ammonia, flowing through a heat exchanger (evaporator). The vapor expands at moderate pressures and turns a turbine coupled to a generator that produces electricity. The vapor is then condensed in another heat exchanger (condenser) using cold seawater pumped from the ocean's depths through a cold-water pipe. The condensed working fluid is pumped back to the evaporator to repeat the cycle. The working fluid remains in a closed system and circulates continuously.

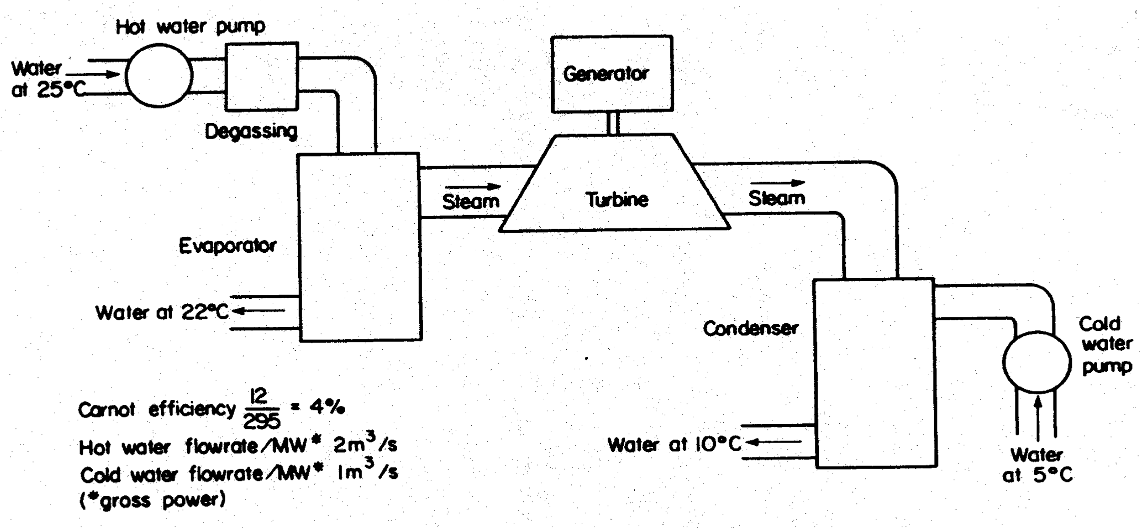
Open-Cycle OTEC System



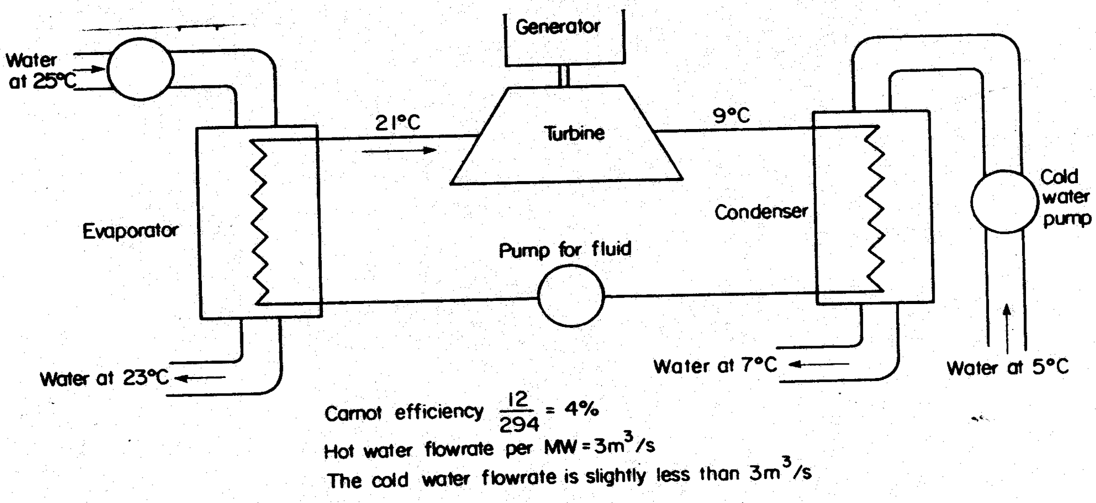
In an open-cycle OTEC system, warm seawater is the working fluid. The warm seawater is "flash"-evaporated in a vacuum chamber to produce steam at an absolute pressure of about 2.4 kilopascals (kPa). The steam expands through a low-pressure turbine that is coupled to a generator to produce electricity.

Source: National Renewable Energy Laboratory

FIG. 3.2. OTEC system designs



Operating principle of an open circuit OTEC plant

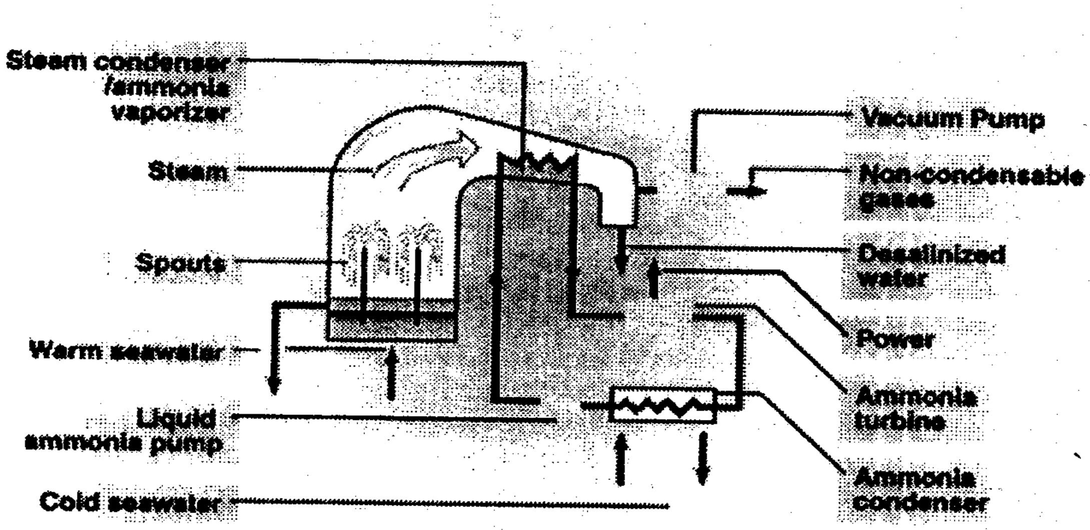


Operating principle of an intermediate fluid OTEC plant

Source: Brin, 1981, p.93

FIG. 3.3. Open and closed cycle OTEC plants

Hybrid OTEC System



A hybrid cycle combines the features of both the closed-cycle and open-cycle systems. In a hybrid OTEC system, warm seawater enters a vacuum chamber where it is flash-evaporated into steam, which is similar to the open-cycle evaporation process. The steam vaporizes the working fluid of a closed-cycle loop on the other side of an ammonia vaporizer. The vaporized fluid then drives a turbine that produces electricity. The steam condenses within the heat exchanger and provides desalinated water.

Source: National Renewable Energy Laboratory

FIG. 3.4. Hybrid OTEC system

Environmental effects

OTEC systems have some mild negative effects to the environment. For instance, they bring local dislocation of ecosystems. But the effect is reduced as it is compensated for by the nutrient-rich cold water brought up by the cold water pipe. OTEC sites become slightly toxic due to corrosion of the metals of the heat exchangers and anti-fouling agents, and fluid leaks. There is also the problem of oceanic effects from the transfer of heat from surface to deeper water. Local climatic change could also occur if the carbon dioxide in the deep cold water is released to the atmosphere in large quantities.

3.2.2 WAVE ENERGY SYSTEMS

A wave is a raised mass of water on the surface of the ocean that is caused by wind. Waves are actually energy. Energy, not water moves across the ocean's surface. Careful observation shows that as the wave (energy) moves to the shore, water particles do not move with the wave. But rather the particles move in small circles as the wave passes. The wave energy is finally released on shorelines.

Since wave is energy in motion, its size can be measured. The size of the wave depends on:

- The speed of the wind
- The length of time the wind blows
- The distance (or fetch) the wind blows over open water

All the three factors are proportional to the size of the wave. In other words, the greater these three the bigger is the wave (The Evergreen Project, Inc., 1995, p.1).

Since wave is a form of energy it can therefore be converted into another form, say electricity. The generation of electricity from the motion of waves has been under consideration for a long time, because of its potential as a source of electricity. Unfortunately waves must be of certain size for it to be of use in electricity generation.

Some locations in the world are blessed with strong waves while some are not. Therefore, wave energy schemes are only applicable to specific sites, that is, where the wave -energy is recoverable.

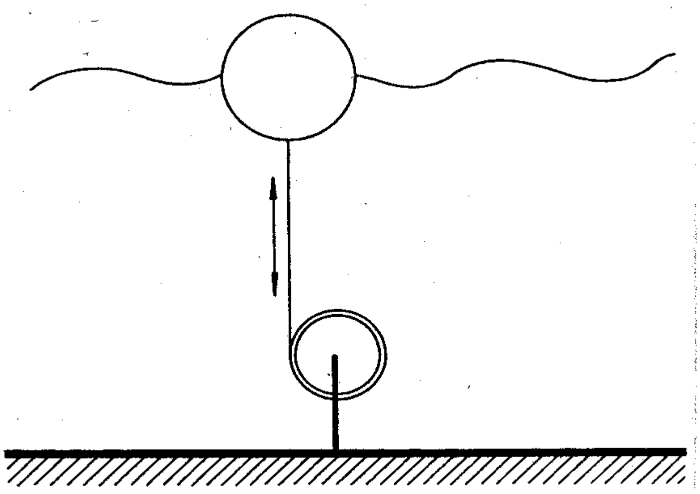
Recovery Devices

In order to convert wave-energy to mechanical or electrical energy inventors developed or proposed large number of systems. The systems are many. Therefore, only the important ones that form the basis of the rest would be treated here.

Floating Buoy

Many designs for harnessing wave energy have been produced. Most of the designs were based on the motion of a floating buoy that rises and falls with the waves. The energy of the wave's upward movement is imparted to the buoy (also called a float). Thus, the buoy moves up and down. The mechanical energy of the buoy turns the generator to convert mechanical energy into electricity. The efficiency of the system depends on how efficient the floating buoy is in removing as much energy as possible from the incoming wave. Floating buoy are made so sophisticated to extract all the energy from the wave.

The diagram of a simple float (buoy) system is shown below in FIG. 3.5. The float is driven by waves' vertical motion, an oscillation that can be transferred into alternating rotary movement by means of pulley.



Operating principle of oscillating float Source: Brin . p. 106

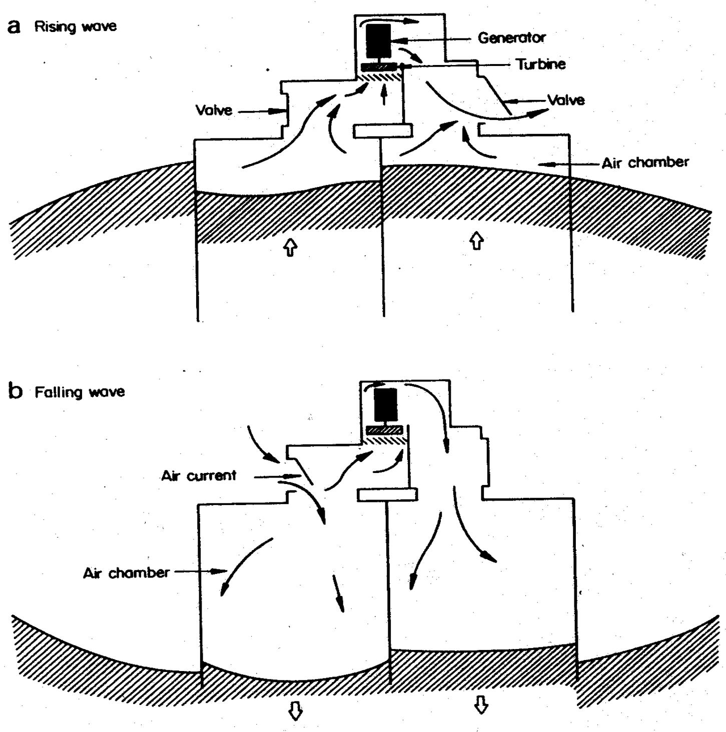
FIG. 3.5. Oscillating float

One import disadvantage of the float system is that it is an electro-mechanical device by which wave movement is conveyed mechanically to a generator that then transforms the mechanical energy into electricity. Thermodynamic limits and frictional losses are set back to the overall efficiency of the system.

Moving System

In this device force is exerted on the piston that is enclosed in a bell as the wave passes. The force is alternated as high and low, similar to the sinusoidal nature of wave motion. The bell is maintained at a fixed distance from the seabed and is fitted with an orifice or a vent. Through this vent air is alternatively expelled or drawn in it as the piston moves according to the motion of the wave. Essentially air is continuously being displaced. This displacement of air is used to drive a turbo-generator.

Because of the alternating nature of waves, the direction of rotation of the turbine is reversed at each half period of swell. In order to utilize the motions in both directions, two circuits are provided for supplying the turbine. One circuit corresponds to the passage of the crest of the wave and the other to the trough. The pressure valves controls the movement of air (see diagram in FIG. 3.6.). This enables the turbine to receive air flows that are in the same direction.



Device for recovering wave energy using a moving piston, consisting of two chambers coupled to a single turbine. By using a system of valves, the direction of the air through the turbine can be kept the same (*after Energy of Swell, La Recherche, May 1978*)

Source: Brin, 1981, p.107

FIG. 3.6. Moving piston device

Using this principle power in the range of several tens of watts has been generated.

There are several countries that have worked for this type of generator. For example, Japan, Canada, England and Israel. But the work in Japan has been most significant. Under the Masuda Project, a 2MW system was produced in the beginning. It was named *kaimei.* It was a 500-ton pontoon, 80m long and was carrying 22 compression chambers which could be coupled in pairs to eleven turbines. The *kaimei* was tested with electrical equipment on a reduced scale. The results were satisfactory (Brin, 1985, p.106).

Lanchester Clam system

Another typical recovery device is the Lanchester Clam shown below in FIG. 3.7. It uses air turbine to generate electricity. The device mainly consists of huge rubber bags, each connected to a separate *wells* turbine. The bags and the turbines are being supported by a floating hollow concrete beam. As the water waves press on the rubber bags air is squeezed into a common duct or pipe. The squeezed air forces the turbines to rotate. When the waves retreat, the bag pressure drops and it is refilled with air from the common duct. The whole process repeats itself as the rubber bags fill and empty air through the duct.

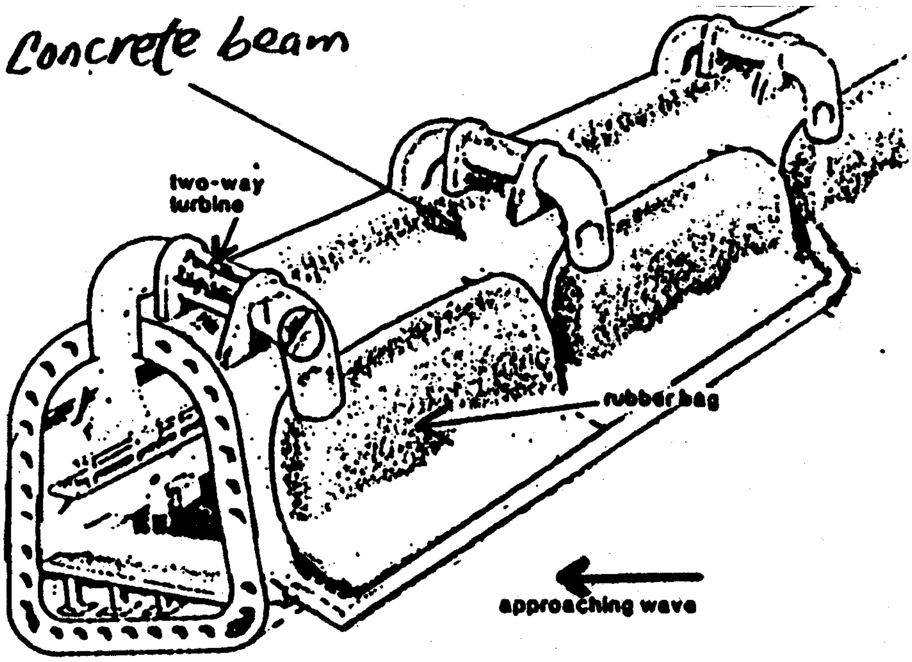


FIG. 3.7. Lanchester Clam system

Research and development of wave-energy systems has been going on in various countries. The aim is to design and produce an efficient and effective energy systems that are better than the previous ones. As a rule the system should have the following general objectives (Wick et al., 1981, p. 76):

- The wave motor must be located relatively near to land with maximum exposure to locally generated and swell waves.
- Ideally, the wave motor should have a flat calm on the lee side. This requires that a wave motor completely absorb wave power to a depth where the orbital motion is negligible.
- The wave motor must respond efficiently to the range of wave heights and periods occurring within a given sea state as well as to the wide range of sea states that will occur with the passage of storms. In other words, it must be part of untuned, non-resonant system.

The recovery device itself should specifically be designed with consideration given to the following:

- The motion resulting from wave actin are relatively small and of low velocity.
- Therefore, air turbines may be relatively inefficient. Similarly, systems making use of the relative motion of a magnetic fields and coils will be relatively inefficient because of low velocities.
- The motion occurring during any given sea state will vary considerably and will be far from regular. Piston movement, for example, must allow for the maximum wave height which could be two times the value of the significant wave height.

Difficulties Associated With Wave Energy Systems

Wave energy systems are usually massive and voluminous. They also require a very large area to be sited. For instance, *Wave Power Limited* of the United Kingdom proposed a raft for the country that would be 100m long, 50m wide and 8m deep! If made of steel it would weigh 3,300 tons and would require 12,000 tons of ballast (Wick et al., 1981, p. 76).

Wave power recovery systems must be rugged and must have the capacity to respond to wave motion. These make them difficult to construct. Furthermore, they should be designed is such a way that they will work in very irregular wave motions and pressures.

The energy generated by these systems fluctuates, as such storage and transmissions are difficult to remote areas. Therefore the energy is better utilized in site. For example, for hydrogen generation plants, desalination plants or for the operation of a sea based aluminum smelter.

Another problem with wave-energy systems is the cost. As at now it is more expensive than land based power stations. But it is hoped that it would be cheaper in the near future, especially when the prices of non-renewable fossil fuel rise.

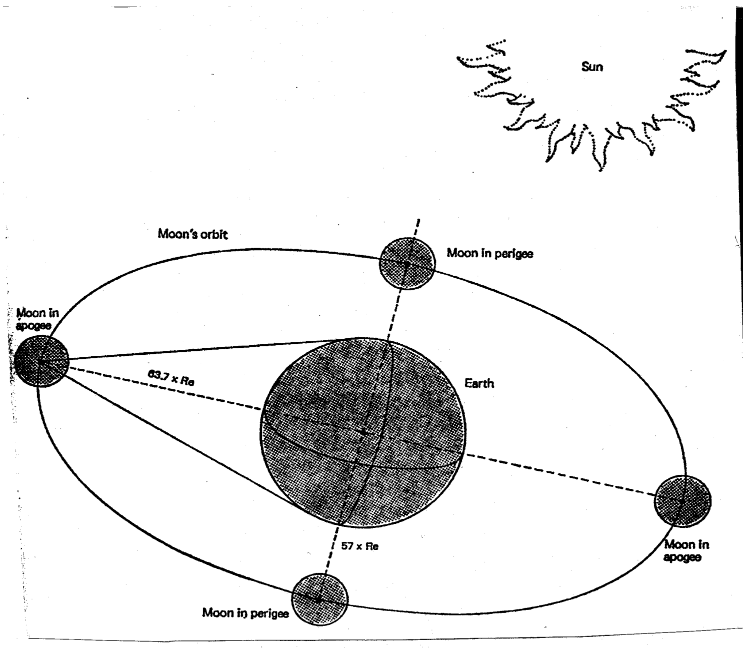
Environmental effects

Wave energy systems have hardly any harmful effects to the environment. They are essentially clean and non-polluting. On the contrary, wave energy systems encourage migration of fish and other marine animals to the site because it gives them some sort of shelter.

3.2.3 TIDAL ENERGY SYSTEMS

Tides are produced by the gravitational pull of the sun and the moon on the oceans of the rotating earth. The moon has the predominant influence. Tides of varying amounts of force can be found on any coastline and in the open sea. When the tide is coming in or rising it is called a flood tide. When it is going out it is referred to as an ebb tide (The Environment Homepage, 1998, p. 1).

The amplitude of tides vary from one place to the other. As tide moves closer to shore its amplitude can be as high as twelve meters. This depends on local features such as shelving or funneling. Hence, tides are low or high only at certain areas of the world. The magnitude of the gravitational force acting on the oceans is not constant. The forces are constantly changing due to the relative positions of the sun, the moon and the earth. This explains why the amplitude of tides varys. Refer to the sketch in FIG. 3.8 showing the moon at perigee and at apogee (Wick et al, 1981, p.31).



The moon at different positions (source: Wick et al.)

FIG. 3.8. The moon at perigee and apogee

The moon makes two different motions. It does orbital journey around the earth every 29.54 days. And also makes one complete revolution about its own axis every 24hr 50min. Every 12hr 25min. a tidal cycle is completed. Therefore, within the lunar day of 24hr 50min. two tidal cycles are completed and are called semidiurnal. The moon comes in line with the sun and the earth every 14.8 days, first on the side facing the sun and then on the side away from the sun. these are the times of new moon and the full moon. And these are the times when spring tides come. Neap tides occur when the sun and the moon are 90° out of phase. As the moon comes closest to the earth (i.e. in perigee), the larger spring tides will occur. But when the moon is farthest from the earth (i.e. in apogee), the smaller neap tides will occur. The maximum tidal range at a particular place will occur during the equinoxes in March and September each year, when the length of the day equals that of the night.

Tides are never equal either during the day or night due to the effects of the moon and the sun. Tides are also affected by the *coriolis* force. This is the force exerted by the rotation of the earth on a moving stream that causes the water to slope on one shore. Offshore storms and hurricane affects the amplitude of tides. This results in severe flooding of low coastal areas.

There are two methods of turning tidal power into electricity. These are the Tide Mills System and the Barrage System.

Tide Mills

The water brought by the incoming tides is made to pass through openings or sluices into a storage pond. When the tides go back out, the water flows back into the sea through a water wheel. Thus, the water wheel is turned mechanically.

Barrage System

This is more or less similar to the tide mills. It consists of a dam or barrage built across an estuary. Water brought by the tide is trapped in the dam at a higher level. The water is then willingly released to a lower level where it turns low-head axial turbines.

Modes of Operation of Tidal Power Systems

Over the years scientists and engineers tried many ways of converting tidal power into mechanical/electrical energy. All the ideas concepted and designed can basically be grouped into two systems. These are the single effect (one-way tide working) and double effect (two- way tide working).

- Single Effect System/Single Basin- This utilizes either the ebb or the flood tide to generate power but not both. The plan is simple and results in the lowest energy cost. It has bee n discovered that the ebb tide produces more energy than the flood tide. In the ebb tide operation, the basin would be nearly full at the start of the generating cycle, and would gradually be lowered until it is about half full in height at the end of generation. This gives rise to longer period of generation with corresponding increase of energy output.
- Double Effect System/Single Basin-In this arrangement, two basins are hydraulically linked to one another. It is more common in use because it produces continuous tidal energy. Here one basin becomes the high pool and the other the low pool. The single effect flow is always from high pool to low pool. At flood tide the water goes into high pool. At ebb tide the water drains from the low pool back into the sea. This cycle is repeated continuously.

Note that just as it is possible to connect two pools hydraulically as described above, it is also possible to link two single effect schemes electrically. However, they should be located close to each other. In this arrangement one basin is usually operated with flow from the basin to the sea at ebb tide, while the other operates with flow from the sea into the into the basin at low tide.

Existing tidal energy systems

Based on the scientific knowledge on how to extract tidal energy, China, Russia and France have already built tidal plants of significant sizes (Wick et al, 1981, p.33).

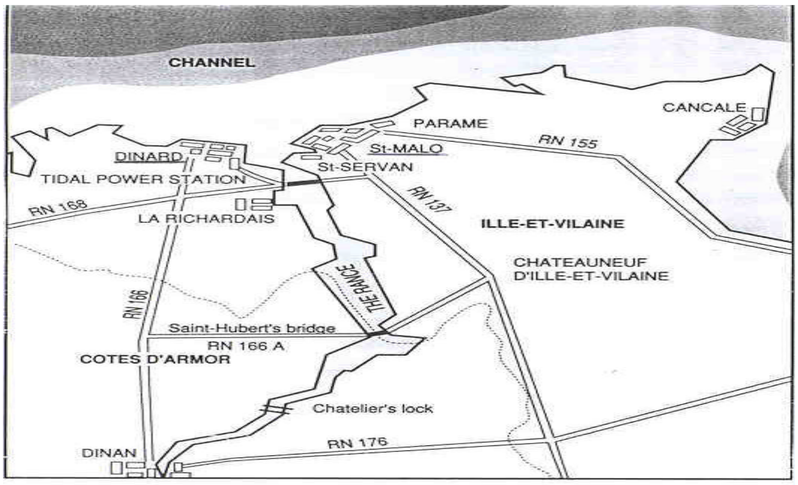
In 1958 China had forty tidal plants that have a combined capacity of 583 KW. Later eighty more plants were built with a total capacity of 7,005 KW. The largest plant is located at Taliang, with three 48 KW units operating between an upper and lower basin and five 32KW units operating between the lower basin and the Shunte River.

In 1968 Russia had built a bulb-turbine of 400 KW capacity, with the aim of harnessing tidal energy. The power plant was located at Kislaya Guba in the Gulf of Ura.

In 1967 France had built the most impressive tidal energy system. The plant was located in the Rance Estuary near St Malo. The plant has 24 bulb-tirbines with a total capacity of 240 MW. Each turbine is capable of using both the ebb and the flood tides under the operating heads as low as 1.5m. But the mean tide range is about 8.5m, while the maximum spring tides can be as high as 13.5m.

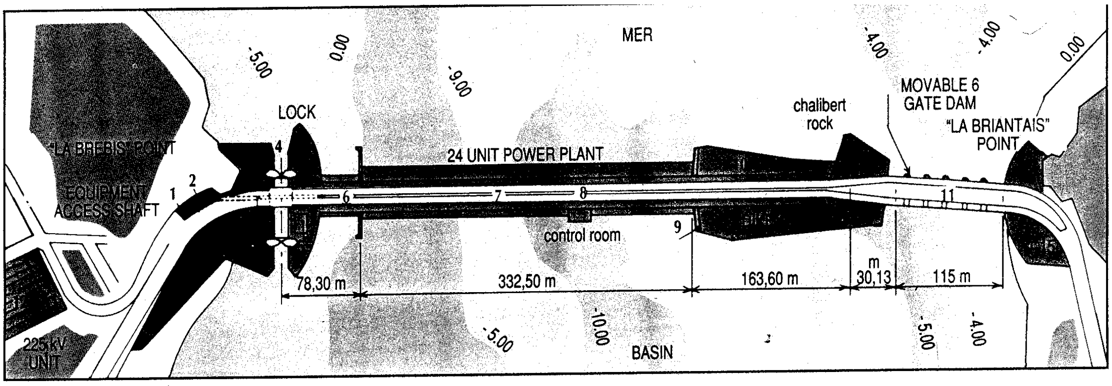
The French power plant is very big and interesting. It attracts about a million tourists every five years. It provides effective shot-cut between St Malo and Dinard to about about a million motorists every two months, especially in summer. This is because of the four-lane roadway built on top of the barrage structures.

The location of the plant is shown in FIG. 3.9. The four-lane road connecting Dinard and St. Malo over the barrage is marked black. FIG. 3.10 shows the structure of the plant as a whole and that of the bulb-turbine.



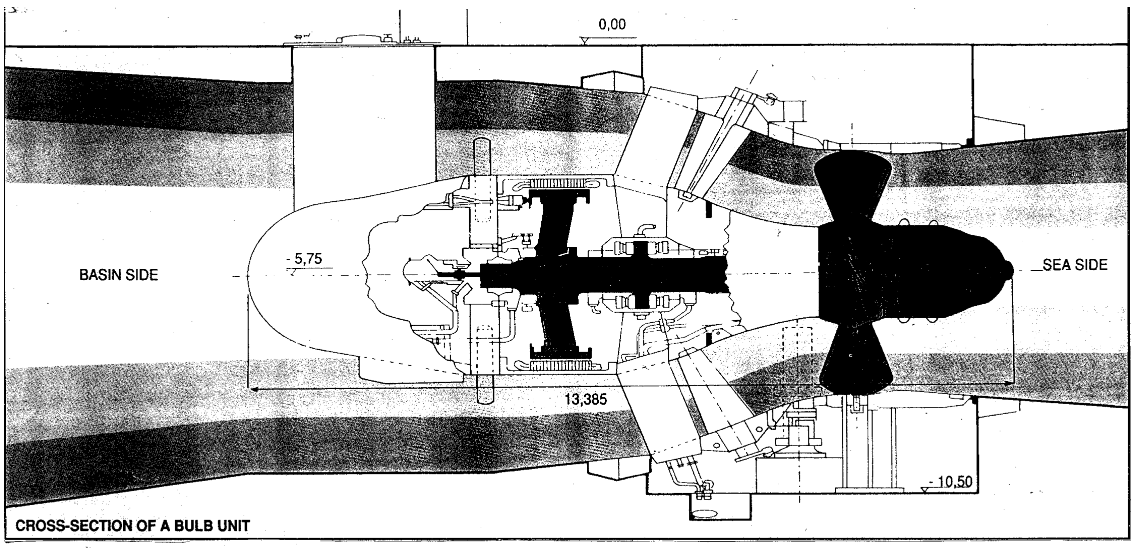
Location of the Rance tidal power plant in France

FIG. 3.9. Location of the French Rance



1 Access building for large equipment floor at + 16,65 m level (marine charts)
2 Shaft for descent to rooms at level - 7.00 m diameter 12 m
3 Access gallery at - 7.00 m, passing under the lock, about 80 m long
4 Navigation lock, lock chamber : 65 x 13 m, invert at + 2.00 m
5 Administrative building and main access to the plant
6 Equipment disassembly bays and maintenance shops
7 24 bulb-unit bays, distant 13.30 m from each other
8 Control bay
9 Wall at plant end, constituting the retaining wall of the rock-fill dike
10 Rock-fill dike
11 Six sluices equipped with 15 x 10 m gates
12 Line departure unit, three 225.000 V lines

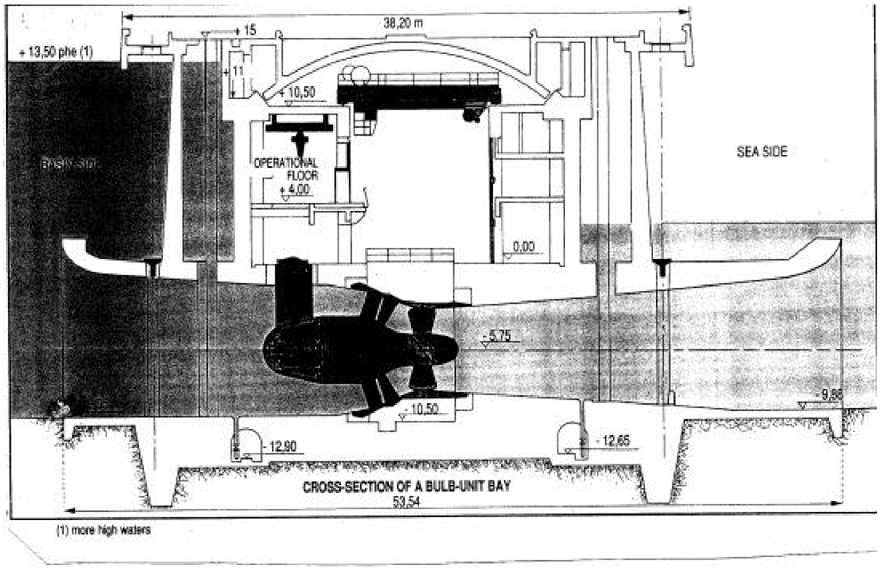
Structure of the Rance Tidal Power Project (source: The French Tidal Power Project)



Structure of the bulb-turbine (source: The French Tidal Power project)

FIG. 3.10. Structure of the Rance project and that of the bulb-turbine

The machinery room of the power plant consists of a reinforced-concrete chamber hollowed out in the dyke (thick wall), 390m long and 33m wide between the extreme wall faces. The room is divided into 28 bays (or compartments) by buttresses spaced 13.30m apart and is covered by a vault supporting the road. The first three bays, the closest to the lock, are occupied by maintenance shops and disassembly areas. The 25 following bays house the 24 bulb-turbines, the 3 main transformers and the control room. The diagram showing the cross-section of a bulb-turbine bay is as shown in FIG. 3.11.



Cross-section of the bulb-turbine bay (source: The French Tidal Power Project)

FIG. 3.11. Cross-section of the bulb-turbine bay

Advantages of tidal power plants

Because of the foreseen or experienced advantages of tidal power plants a lot of countries have developed the technology for building them. For example, USA, China, France, UK, Russia and Canada. Furthermore, France has built a 240MW Rance Tidal

Power Station in order to show the feasibility of the new technology for producing electricity.

Despite the fact that tidal energy is currently more expensive it is likely to be a favored energy source in the near future. Its advantages can be summarized as follows (Wick et al., 1981, p.50):

- It requires no fuel after construction.
- It causes virtually no air or water pollution.
- It requires small land area.
- It has very high plant reliability.
- It has long plant life.
- It has very small environmental impact.
- It is very safe
- It has power output that is both predictable and dependable.

Environmental effects

Tidal energy systems require a dam which implies increase of the temperature of the water and reduction of oxygen content. This is harmful to marine life. Dams affect fish migration and have damaging consequences for fisheries. Otherwise the systems are environmentally friendly.

3.2.4 SALINITY ENERGY

Salinity has been defined as the amount of salt per liter of water. It is expressed either as parts per million or ppm (equivalent to mg/L) for low salinity, or as parts per kilo or ppk (equivalent to g/L) for high salinity. There are meters for measuring salinity for different purposes. The salinity of seawater is 36 ppk (TPS Tpy Ltd., 1996). This amount of salt is just enough to provide the salinity gradient to generate electricity.

Salinity gradient exist at an area where fresh and salt water meet. For example where a river (fresh water) flows into the ocean (salt water). The difference in salt concentration between the two waters is a power that is represented by the osmotic pressure difference. Just at the interface between the fresh and the salt water a barrier or semi-permeable membrane exist that permits passage of water, but not salt. As a rule, the water will flow from the low concentrated side(fresh water) to the high concentrated side(salt water). Thus, the surface level of the concentrated solution will be raised by this flow until the pressure due to its elevation equals the osmotic pressure difference. At this point the flow stops. The elevated salt water(sea water) can then be released onto a turbo-generator to produce electricity(Wick et al, 1987, p.111).

Salinity energy is renewable because there is always a flow of water from rivers into the oceans. And the salinity of the ocean remain constant as the result of sea water evaporation and subsequent precipitation over land. Therefore, salinity gradient is a potential energy source.

Another way of understanding the existence of salinity energy is considering the fact that fresh water can be obtained from sea water(desalination) using various methods, all of which require a net input of energy. It follows that when the desalination process is reversed energy would be released. Based on this principle two bodies of water of different salinity can be mixed to get energy. The two bodies of water mix naturally at points where rivers join the sea.

Few methods have so far been developed to extract or recover salinity energy.

Methods of recovery

From the salinity of sea water(36 ppk) a pressure head of about 240m or 24 atmospheres exist which is enough to generate electricity by any of the recovery methods.

Direct Mechanical Method (Brute-Force Method)

This method is based purely on the principle of osmotic pressure. It requires large and massive structures. According to Wick (Wick et al, 1981, p.116) 'river water is allowed to flow through hydro-electric turbines into a reservoir at a level which is some 200 meters below sea level. The difference in heights between the reservoir and the sea is maintained by the osmotic pressure difference. Ideally, it could be as much as 240 meters, but it should be sufficiently lower than the osmotic equilibrium level (240 meters) to allow the discharge of fresh water directly into the salt water (ocean) through semi-permeable membranes (membranes permeable to water but not dissolved solids like salt). These membranes must be washed continuously by large volumes of ocean water in order to carry away fresh water and prevent *concentration polarization* due to dilution of the salt water adjacent to membrane surfaces'. A schematic diagram showing the Brute-Force method for extracting salinity power is shown in FIG. 3.12.

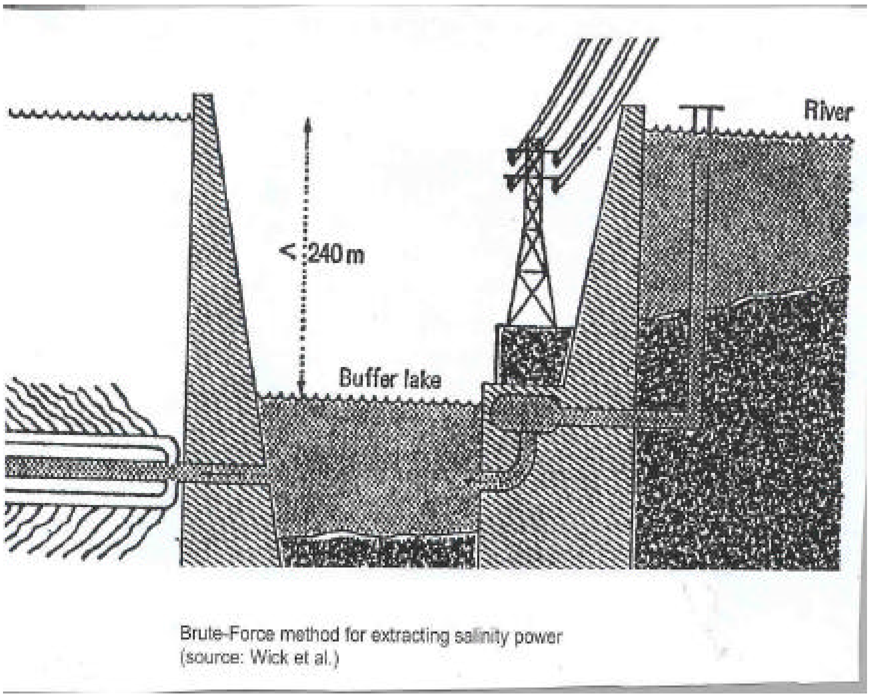


FIG: 3.12. Brute-Force method

This method has some disadvantages, namely:

- It is uneconomical as the capital cost per kilowatt would be at least 36 times higher than the cost of a conventional power plant.
- It requires the construction of huge plant much of which is 200 meters below sea level.
- High cost and maintenance of the semi-permeable membrane affect the cost of electricity produced.
- Accommodation of biological fouling affects the environment.

Pressure-retarded osmosis method

In this method the sea water is pumped to a hydraulic pressure of about 200 atmospheres which is less than the osmotic pressure difference (about 500 atmospheres) between the sea water and the fresh river water. Since the two waters are separated by semi-permeable membranes the fresh water would diffuse into the pressurized sea water, raising the total volume of the mixture (sea water plus fresh water). The mixture is again subjected to hydraulic pressure and could do work when passed over a turbine.

This method produces energy at a higher cost than conventional power plants. But experts believe that further technical improvement would make the method economically feasible.

Dialitic method

This method is based on the reverse process of electrolysis that is used in desalination in which two fluids of different salinity are separated by an electrically conducting membrane, connected to an electric circuit. The ion transfer between the fluids sets a potential difference (electric voltage). The potential varies with the salt concentration of the fluids. For example, a voltage of about 80 millivolts exist when the salinity of fresh water is 850 ppm and that of sea water 35,000 ppm. This amount of voltage is only for one dialytic cell. Higher amounts can be achieved when many cells are put together in series.

The problem with the reverse-electrodialysis in producing electricity is the cost of the membranes. They are too expensive and the cost would affect the price of energy produced. Further research and improvement on design techniques could hopefully bring the prices down. For example, there was a plan to build a reverse-electrodialysis plant on Sweden's western coast. The design was produced by two scientists from the University of Gothenburg (Wick et al, 1981, p.123). It has been speculated that the price of generated electricity would compare favourably with the current prices of electricity generated by nuclear plants.

Expansion and contraction method

Collagen is a substance that has the ability to expand when in contact with fresh water and contracts when in contact with salt water, or vice versa. There are other substances that exhibit this property. But collagen is specifically mentioned here because it is well known, as it is a major component in animals' muscles and tendons. Such substances can be made to move pistons up and down as they expand and contract repeatedly. The moving piston can be connected to a flywheel or to a turbo-generator.

This concept is at its infancy at the moment. Further attention to this idea would yield a fruitful result in producing alternative source of energy, no matter how small the energy may be.

Vapour pressure method

Ocean thermal energy conversion (OTEC) is a power generator that operates between the heat reservoirs of cold deep ocean water and the warm surface water. The temperature gradient or difference yields the vapour pressure difference used to turn a turbine. Such power generators may have greater potential if they exploit the vapour pressure differences between sea water and brine (of higher salinity than sea water) rather than those differences between warm and cold water. Whereas OTEC requires a temperature difference of 20°C or more to operate, this new arrangement requires just 12°C. At this temperature the vapour pressure difference is about 7mm of mercury or 0.01 atmospheres that can be used to turn a turbo-generator.

Experimental models have demonstrated the viability of vapour pressure method. It would yield more power than the reverse electrodialysis method. A significant feature of the vapour pressure method is that it requires no semi-permeable membranes. The water surface acts as the membranes. Thus, this eliminates the problems associated with membranes such as high cost and deterioration.

It is important to note that to generate electricity from salinity gradients two bodies of waters are required, for instance, fresh river water and salty sea water. Where a river is not available, sea water can be used (as the fresh water) and brine (as salty water).

Environmental effects

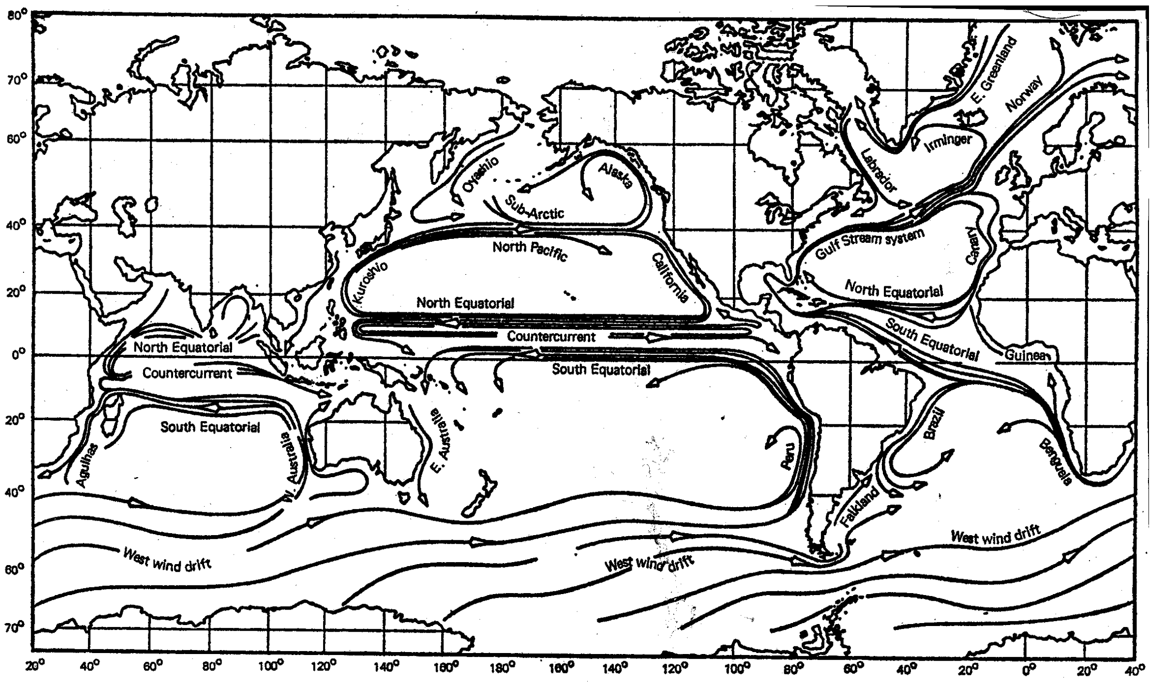
Usually human developments around estuaries have some effects to the marine environment. But careful environmental impact assessment and good planning mitigate these effects.

Erecting huge reservoirs in estuaries would result in putting them under more stress, as they are very productive, and are the primary breeding places of marine life. Marine life would also suffer being sucked into the inlet pipes, major components of salinity energy plants.

3.7 OCEAN-CURRENT ENERGY

There are some areas of the ocean that possess so much kinetic energy that sets large bodies of water flowing with high speeds. The energy in the current is great, so is the speed which may reach up to 2.5m/s (or 9km/h) in some areas. The energy of the ocean-current can be tapped by placing turbines in the direction of the flow.

Some of the few areas with major oceanic currents are the Gulf Stream in the North Atlantic (off eastern North America), the Kuroshivo in the North Pacific (off eastern Japan) and the Agulhas in the South Atlantic (off southern Africa).   FIG.   3.13 shows major oceanic currents of the world.



Major oceanic currents of the world (source: Wick et al.)

FIG.   3.13.   World oceanic currents

There has been a proposal to harness the energy of the ocean current in the USA called *Coriolis One*.   The diagram of the prototype is shown in FIG.   3.14.   The aim was to recover part of the energy of the Florida current, shown in FIG.   3.15.   In the proposal an array of 242 huge turbines would be placed in the current over an area of

1800 square kilometers of the coast of Florida. Each turbine would be 170 meters in diameter and 100 meters in length, with rotor blades 90 meters in diameter. The corresponding output of each turbine would be 83 MW (Ford et al, 1987, p.185). The United States government has keen interest on this project as it is hoped to be economically competitive with other ocean energy systems, and would have minimal environmental effects.

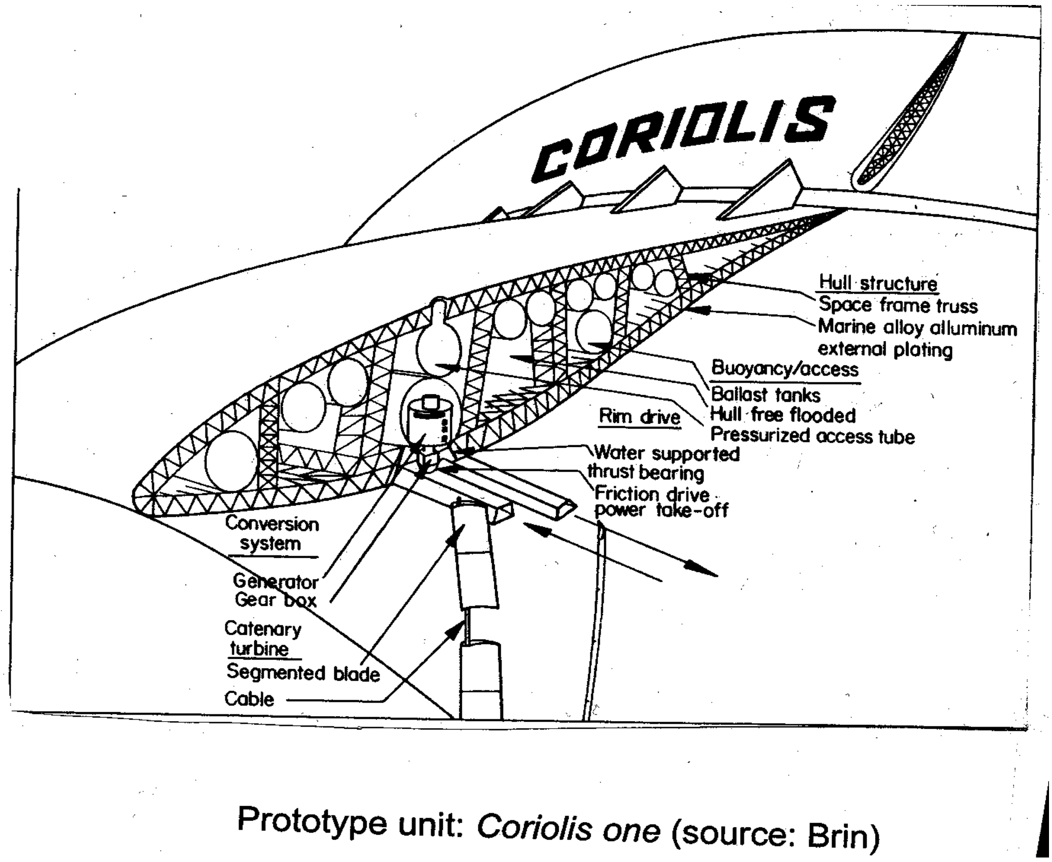
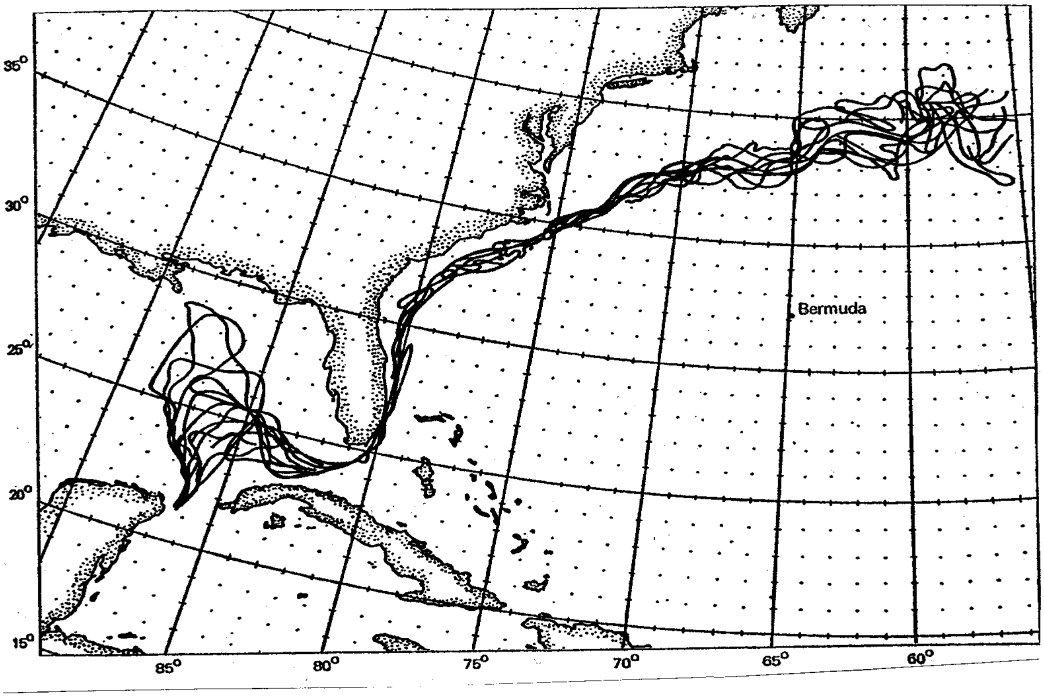


FIG. 3.14 Coriolis One



Florida ocean currents (source: Wick et al.)

FIG. 3.15. Florida ocean currents

Japan also is considering a similar project to tap the energy of the Kuroshivo currents. This would further help to overcome the technical difficulties and make the whole concept a reality within the next decade or so.

Environmental effects

Placing large turbines in series, suspended about 30 meters below the ocean surface would reduce the normal speed of the ocean-current by one per cent. Even though the amount is small, there is no data to prove that it would have no effect on the natural behavior of the as a whole. Another problem is the possibility of killing large marine animals, for example, whales that could move into the rotating blades of the turbines.

There is also the problem of dissipation of heat to the sea through the operation of the turbines that may affect marine fauna and flora.

3.2.6 DENSITY-GRADIENT ENERGY

Extrapolating from salinity gradients of the ocean, the ocean can also be examined according to different density gradients. The density gradients are consequent upon temperature differences, either from the cold water of melting ice in warmer seas or from hot springs producing localized temperature differences in comparison with the temperature of the surrounding water. 'It is from the density gradients consequent upon these temperature differences rather than the temperature differences themselves (as in OTEC) that energy could theoretically be extracted' (Ford et al, 1987, p. 86).

Production of electricity from the density gradients of the ocean still remains on the drawing board. No prototype has been built yet. Scientists believe that it would be a promising source of energy in the future.

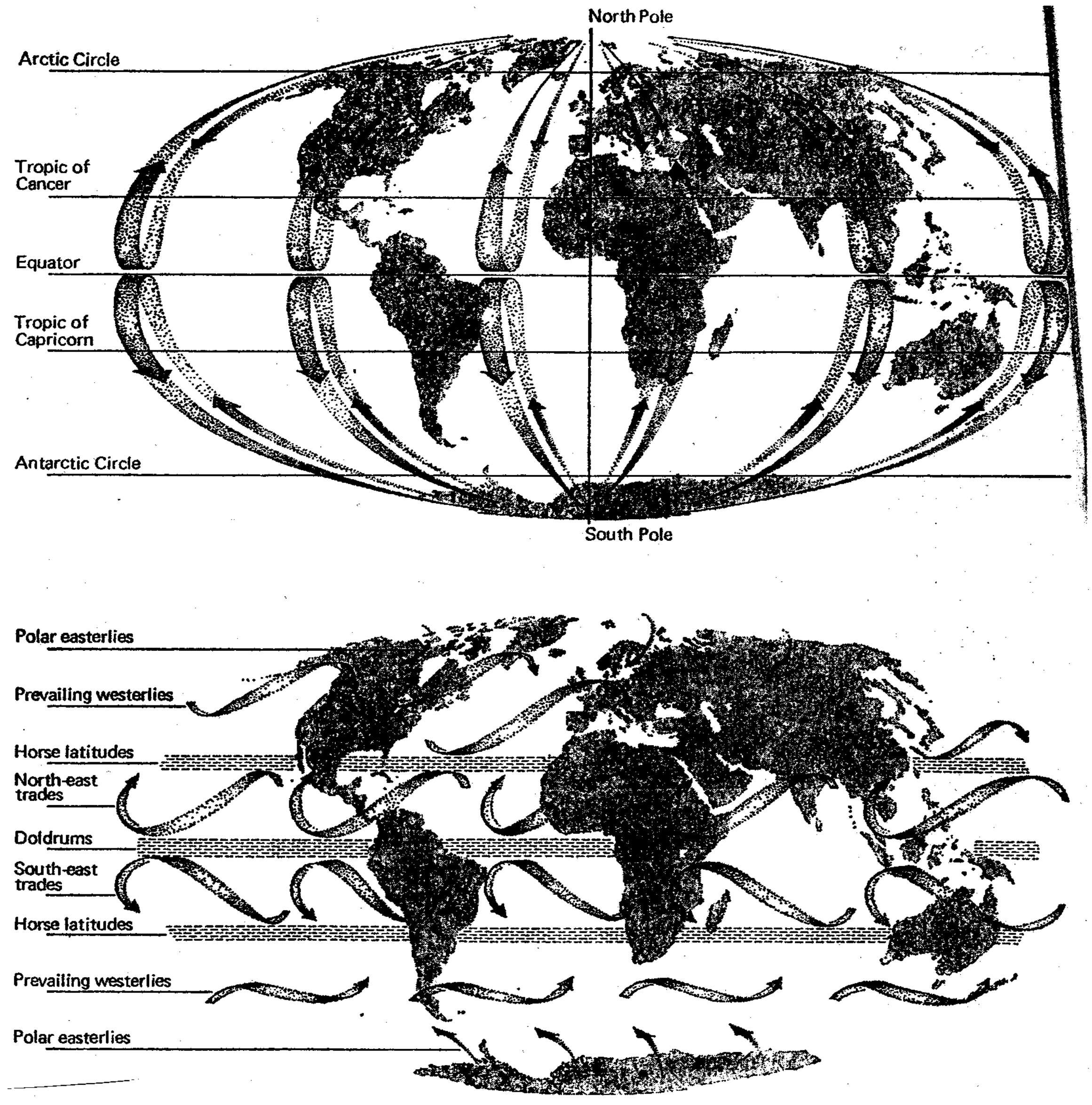
Environmental effects

The effects of density energy systems to the marine environment have not yet been fully assessed. The effects are expected to be similar to those discussed under ocean thermal energy systems.

3.2.7 OCEAN-WIND ENERGY

The conversion of wind energy has been a well technology for quite sometime. Wind mills, wind electric generators and sail ships are examples of wind conversion devices where wind energy does work. What is also known is the fact that winds blow stronger and more persistently over the sea than over land. Therefore, ocean winds would produce more power than land winds. Ocean winds would be more beneficial in electricity generation since there are big cities lined along coasts.

To tap the energy of ocean winds, array of large wind turbines must be fixed to the bottom of the ocean at a convenient site. The best sites are those close to coastal cities or towns, or small industries. Some coastlines are more favourable than others. Refer to FIG. 3.16 for the world map showing wind circulation over the whole globe.



Wind circulation on a stationary and rotating earth.

Source: Wick et al., 1981, p. 157

FIG. 3.16. World wind circulation

Ocean-wind turbines in the megawatts range must be constructed for commercial electricity generation. The materials to be used in manufacturing them should have the ability to withstand the corrosive nature of marine atmosphere. Denmark and the United States are the leading manufacturers of wind generators. It is hoped that the duo would soon make ocean –wind energy more feasible.

Environmental effects

The environmental effects of ocean wind turbines are believed to be nil. There are no known adverse effects to the oceanic, atmospheric or biological processes in the sea. The heat released by the turbines is negligible, so is the slight decrease in the speed of the ocean winds that are retarded as the result of rotating the blades of the turbines.

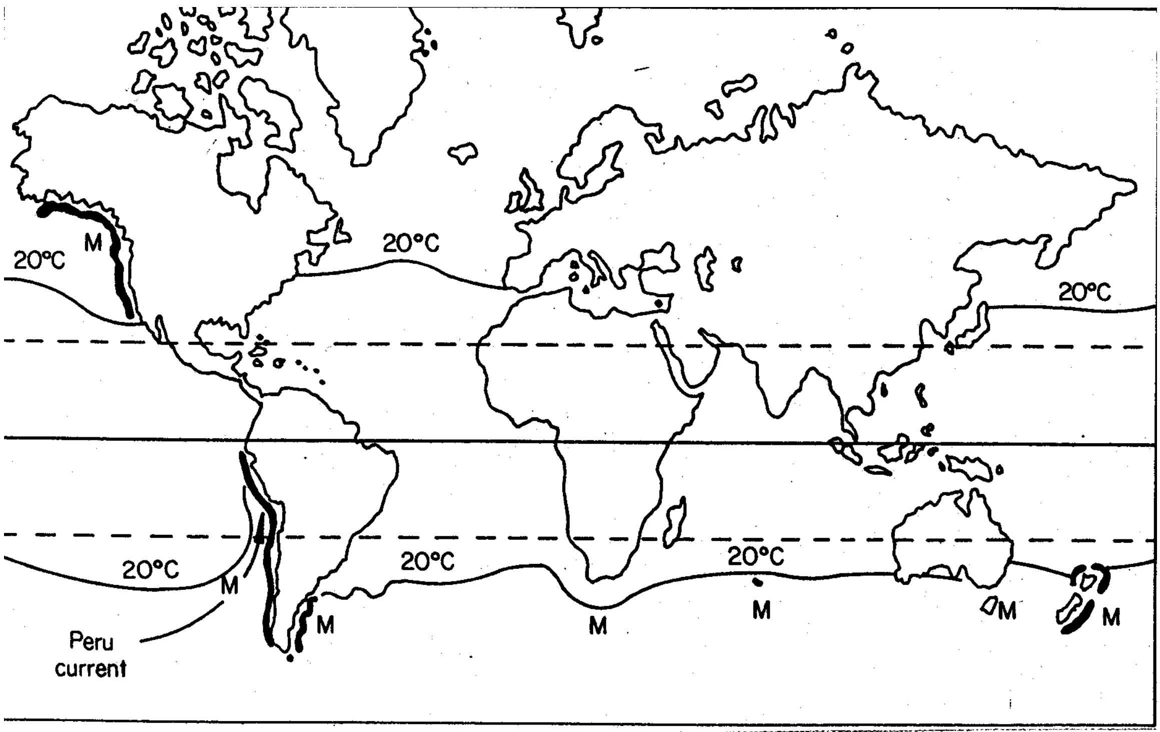
Bird lovers are of the opinion that wind turbines may injure or kill birds especially when the turbines are arrayed along migratory routes. This may not necessarily be correct since migratory birds have the ability to detect and evade the turbines from the faint but audible sounds the turbines produce.

Siting array of large turbines may pose danger to shipping activities. Ships may collide with the heavy structures that are necessary to support the turbines. This may be avoided if the structures are appropriately marked, for example, with beacons.

3.2.8 BIOMASS ENERGY

This is based on the principle that exploits the high efficiency of marine food chains to produce biomass (weight of living tissues) from the nutrients of the sea water. The biomass could be the build up of several species ranging from micro-organisms such as algae through to large marine plants like kelp (Ford et al, 1987, p. 87). The amount of biomass produced per annum is in hundreds of billions of tonnes. Biomass can be harvested and be chemically converted into organic acids and to olefins and hydrocarbons, mainly methane. The end product, methane can therefore be used in thermal electricity plants for electricity production.

The best sites to harvest biomass are those zones where giant algae grow naturally. Refer to FIG. 3.17 showing production zones for the giant alga. Since natural production of algae is limited, it can be cultivated in deep water where it is required. Biomass energy production could prosperous. It has been estimated that the cultivation of giant algae over an area of 140 000 square kilometers would cover the needs of the USA for natural gas (Brin, 1981,p.124).



Production zones for giant alga (source: Brin, 1981, p.122)

FIG. 3.17. Production zones for giant alga

Environmental effects

Biomass is produced naturally. It is the product of marine food chains and therefore poses no threats to the marine environment. However, this may not be the case where algae are deliberately cultivated, when fertilizers may have to be used. Excessive use of fertilizers may lead to plankton bloom which is a disaster to marine life.

CHAPTER FOUR

OTEC AS ADDITIONAL ELECTRICITY AOURCE FOR NIGERIA

The National Electric Power Authority (NEPA) of Nigeria has not achieved its aims in providing uninterrupted electricity supply to every home in the country, electricity supply has been had especially with the industrial and urban growth in the country. It is therefore very necessary that Nigeria must continue to explore means of boosting electricity generation. The ocean must now be used. There is no need to depend on only thermal and hydro stations.

4.1 BACKGROUND

The oceans constitute a little more than 70% of the total surface of the earth. Nigeria is blessed in the sense that it boarders the Atlantic ocean. Its coastline extends up to about a thousand kilometres. The oceans are the world's biggest receptacle and storage of solar energy. It has been observed that about 60 million square kilometres of tropical seas absorb an amount of solar radiation that is equivalent to the heat energy of 250 billion barrels of fossil fuel or oil (National Renewable Energy Laboratory, 1999). Nigeria shares this bounty in both the territorial sea and Exclusive Economic Zone (EEZ). An infinite small amount of the solar energy stored in the sea, if utilised through OTEFC can supply in many folds the total amount of electricity demand for Nigeria now and in the future.

4.2 Principles of operation

As described elsewhere in this report, Ocean Thermal Energy Conversion (OTEC) is a new energy technology that is suitable and applicable to Nigeria.

It is the technology that concerts to radiation from the sun to within the EEZ of Nigeria into the much needed electricity in the country. OTEC systems employs the ocean's natural thermal gradient, especially in the Gulf of Guinea to drive a power-producing cycle. The temperature between the warm surface water and cold deep water differs by a substantial amount necessary for OTEC systems. The OTEC system can provide significant amount of power, especially for the heartily industrialised cities of Lagos and Ibadan. The sea is thus and extremely large renewable source of electricity for the country. World wide, the oceans can be utilized to generate billions of watts of electric power, Ocean's potential has been estimated to about 10^{13} watts of base load power generation.

The cold, deep (1000 – 3000m at Gulf of Guinea, Nigeria) seawater to be used in the OTEC system is rich in nutrients, it can be used in marine-culture.

Nigeria has the need and financial capability to build OTEC plant for the supply of electricity, desalinated water (by-product) and various types of marine-culture products.

4.3 The Realities of OTEC Technology

OTEC technology is no longer a fantasy. It is now a proven technology for electricity generation and other benefits as well. Since the proposal of this ingenious technology by a French physicist, Jacques Arsene d'Arsonval, in 1881 a lot has been done to prove that OTEC is a feasible alternative or additional source of electricity.

In 1930, an experimental open-cycle OTEC system was built in Cuba at Matanza Bay by Geoge Claude, the capacity of the mini device was 22 kilowatts fo electricity, Five years later, Claude built another open-cycle plant. The plant was carried on board a vessel moored off the coast of Brazil. Even though there was no data on the power generated, the experiment showed how possible it was to hold OTEC systems on board ships. This achievement attracted the attention of other French researchers in 1956, to design a 3 megawatt open-cycle plant on west African coast near Nigeria. The project was probably a bait for west African states. The attempt was not successful because at that time OTEC could not compete with inexpensive hydroelectric power. And also due to the fact that most of the states are poor.

More research in OTEC technology has yielded better achievements in producing bigger and more efficient systems. For example, in 1976, the number one laboratory and test facility for OTEC systems, the Natural Energy Laboratory of Hawaii (NELHA) constructed a 50 kilowatts OTEC plant on a closed cycle and was mounted on a barge.

In 1980, the United States Department of Energy (DOE) tested a closed-cycle OTEC system on board a converted tanker of the US Navy. Experts were able to prove from the test results how possible it was to built large and efficient heat exchangers. The results also demonstrated how possible it was to operate OTEC systems from slowly moving tankers or barges. The achievement of the project, OTEC 1 made the US to promulgate a law to promote the commercial development of OTEC technology. From there on a lot has been done to make OTEC systems a reality and suitable for tropical countries such as Nigeria. For instance in 1984, the then Solar Energy Research Institute (SERI) invented a special evaporator to convert warm seawater into low-pressure steam for open-cycle plants. The energy conversion efficiencies recorded were as high as 97% (National renewable Energy Laboratory, 199, p.2)

In 1993 at Keahole Pont, Hawaii an open-cycle OTEC system was able to generate 50 kilowatts of electricity. This further demonstrates the feasibility of ocean energy conversion.

In this year (1999), The US Department of energy has been authorized to experiment on an OTEC system that would provide 10 GW of power by the end of 1999 (Grim, 19, p.99). If this becomes successful OTEC would have its markets expanded.

The attention of the world has now been focussed on renewable energy source from the ocean. The more researches on OTEC systems are being carried out the more interesting the idea of ocean energy conversion becomes. Research should be continuos in order to realise the full bneefits of the new technology.

Research requirements for OTEC Systems

Since science and technology are the backbone of OTEC systems, researches could only hasten its development through careful study of what is on the ground with the view to building more efficient systems. In other words researchers need to

- acquire data on the oeration of OTEC systems based on mini or experimental systems
- Based on experimental and test results, develop cold-water pipe technology and form a database of information on materials, design, deployment, and installation.
- Carry out more research on the heat exchanger systems make the heat transfer more efficiently
- Undertake research in the areas of innovative turbine concepts for large machines required for open-cycle system.

- Find ways of reducing the cost of main components of OTEC plants
- Identify and evaluate advanced concepts for ocean thermal energy extraction.

Siting Assessments

There are relevant data that are needed in order to assess and identify sites that area most suitable for OTEC plants. The data are usually obtained from the archives of national oceanographic institute, and through ocean measurements, making use of ships and moored ocean buoys. To decide OTEC plant location details about the environment must be critically analysed.

Laboratory tests are needed also. In essence, commercial OTEC plants must be sited in an environment that is very stable for the smooth running of the systems. Another salient point is the temperature difference between warm surface seawater and the cold deep water. The difference should be about 20C or 68F with in the depth of 1000 meters or less. As far as the temperature differential are concerned, they are only found in the tropics. To be precise, such sites are generally found between latitudes 20 degrees north and 20 degrees south. Nigeria and fifty five other developing countries fall under this band. The United States of America is also blessed to take a portion of this bounty. This explains the keen interests of the US in developing OTEC technology.

The temperature difference required for locating OTEC plant is available within the territorial sea of Nigeria. The difference is greater than 22C this can be verified by looking at the maps on pages X and Y. Both maps show temperature difference in C. Another factor to consider in siting OTEC Plant is the market potential for OTEC products and by-products. The main product which is electricity can be used by industries and cities along the long coast of the country. Other parameters that should be determined include that distribution of temperature include the distribution of temperature and of ocean currents, salinity, dissolved oxygen, PH, nutrients, light transmittance and the nature of the ocean floor. It is also necessary to find out how the operation of an OTEC plant may affect thermal, biological and chemical properties of the plants surrounding vicinity. Whenever such changes are significant, they could affect the optimum efficiency of the plant. For example, continuous circulation of warm/cold water temperature necessary for the OTEC system. Some experts believe that it may even affect the local meteorology. Other effects could be release of large amounts of carbon dioxide into the atmosphere. This is due to the fact that deep water contains higher concentration of carbon dioxide than surface water and a small amount would be released as water is brought up.

4.6 OTEC Plant Design

OTEC technology can be utilised using different designs that suits the environment of the nation concerned. For this reason, different cropped up on how OTEC facilities can be mounted. There are now three options:

- land or close to the shore
- platforms attached to the shelf
- Moorings or free-floating facilities in deep ocean water.

Land-based and close to the shore Facilities

This category would seem more advantageous to Nigeria’s coastal cities and industries. It offers three main advantages over those located in deep water. OTEC plants build on or close to land do not require sophisticated mooring, lengthy power cables, or the more extensive maintenance associated with open-ocean environments. They can easily be stationed in an enclosed areas in order to give them relative safety from storms and other perils of the sea. The generated electricity, desalinated water, and cold but nutrient rich seawater could be transmitted from the plants to the shore with ease and despatch. Another advantage is that land-based or close to shore sites allow OTEC plants to trade with industries such as mariculture or those that require desalinated water.

A land-based OTEC plant could be constructed well inland from the shore. This gives further protection from storms. Plants can also be mounted on a beach. What is generally required is easy access for construction and operation. Land-based sites can also support mariculture. Since the plant is close to land, mariculture products can easily be supplied to markets around.

The negative side of siting OTEC Plants on land close to the sea is the turbulent wave action at the sea shore interface. At this region, the OTEC plants water supply and discharge pipes will be subject to extensive stress during storms and other terrible sea activities. To protect the pipes, deep trenches must be made to bury the pipes deep down, this is an extra cost. Another expense comes because the pipes for discharge of warm and could water must be taken couple of hundreds of metres offshore to reach a proper discharge depth.

OTEC plants should be built just offshore, in an area of the sea that is between 10 and 30 metres deep. This reduces the length of pipes to be used and therefore costs are reduced. And when the intake and discharge pipes are shorter, they become less prone to water turbulence. OTEC plants need to be protected from the marine environment, such as breakwaters and erosion-resistant foundations (National Renewable Energy Laboratory, 1999, p.2)

Shelf-mounted facilities

OTEC plants can be located on a continental shelf at depths up to 100 metres. This has dual advantages. First, it protects the plant from water turbulence close to land, secondly, the plant gets closer access to the cold-water resource, shipyards provide a favourable site where an OTEC plant (Shelf mounted) can be constructed. It can then be located to its permanent location, and then fixed at the bottom of the sea.

There are additional problems in operating a OTEC plant in deep water. This explains why shelf-mounted facilities are not very popular and more costly than land-based facilities. The problems with the shelf-mounted facilities can be enumerated as follows:

Expose to stress in open-ocean conditions
The product is more difficult to deliver.
It requires additional engineering and construction costs since it has to be made to withstand ocean currents and large waves.
Platforms require extensive pilings to maintain a stable base for OTEC operations
Requires long (and therefore costly) underwater cables to deliver electricity from the plant to land.

Floating Facilities

OTEC facilities can operate while floating in the sea. In view of this a number of different types of floating support have been investigated. These include conventional converted ships, barges, semi-submersible platforms and buoys. Any of these versions could be selected based on the manufacturer and the country concerned. The different types of platforms are shown on pages a, b and c.

Floating OTEC facilities are very much favoured especially for systems with a large power capacity. However, large plants are massive and keeping them afloat bring several difficulties. Some of the observed difficulties are:

Large plant is difficult to stabilise.
Mooring the plant in very deep water may create problems with power delivery.
Frequent damage to cables attached to floating platforms, especially during storms.
Difficulty in maintaining cables at depths greater than 1000m.

Similar to shelf-mounted plants, floating plants require a stable base for steady OTEC operation. Major storms and heavy seas can break the vertically suspended could water pipe and interrupt the intake of warm water. In order to guard against this problem, pipes can be made of relatively flexible polyethylene connected to the bottom of the platform with joints or collars. This make it easier to be removed, for example, during heavy storms, to prevent damage. As an alternative to having a warm-water pipe, surface water can be drawn directly into the platform. However, it is necessary to locate the intake carefully to prevent the intake flow from being interrupted during heavy seas when the platform would heave up and down violently (National Renewable Energy laboratory, 1999).

It is worth stressing that platforms need to remain stationary for large OTEC plant to deliver power through the cables. Anchoring such massive plants at a considerable depth is a beg problem to solve. Dynamic anchoring is one possibility, but it would absorb part of the energy provided. But such anchorage must be provided for any extreme conditions which may occur in the area, especially areas that experiences cyclones (Brin, 198)

Because anchoring an OTEC plant poses some difficulties, an alternative designs have been suggested. The plant may be drifting or self-propelled plantships. These ships use their power on board to manufacture energy-intensive products such as hydrogen, methanol, or ammonia. Ammonia is used as the working fluid in OTEC system. A typical drifting or self-propelled plantship is as shown below (Wick et al 19)

4.7 CONNECTION OF THE OTEC POWER TO NATIOAL GRID

At present Nigeria has two national control centres through which power is distributed to consumers from wherever generated. These are the NCC, OSHOBGO, OSUN Sate and NCC, SHIRORO in Niger State, as can be seen on the map. It is therefore most suitable to deliver the proposed OTEC power to it. A submersed cable would be required to transmit electricity form an anchored floating platform to land.

4.8 SOME INPORTANT PARTS OF THE OTEC PLANTS

OTEC plants are normally operated as floating structures having their own power system contained by an ocean platform. The platform is usually connected to shore through a submarine umbilical. It is through this umbilical that the OTEC products in the form of electricity air, ammonia and hydrogen are carried. This indicates how important the submarine umbilical is. Other equally important features of floating OTEC are the could-water pipe, screens and pumps, submarine electrical cable and of course that heat exchanger.

Cold-water pipe

This is a very significant part of OTEC Plants. It is an aqueduct or cold-water pipe through which the system takes in cold seawater. The pipe could be as long as 1000 metres. But the diameter varies according to the size of the OTEC plant. The diameter also depends on the speed of water flow. The higher the speed the smaller the diameter required. For example a could-water pipe of 40 metres is required for plants of 400 MW capacity. But the diameter can always minimised since the water required for the working of the plant is a function of water pump efficiency (velocity).

Building cold-water pipe for OTEC system has never been an easy job. Iat is capital intensive and requires skilled personnel.

The best methods to make cold-water pipe with are those found to withstand high stresses due to ocean currents. Therefore plastic pipes are most preferred. Other suitable materials are steel, lightweight concrete and glass-reinforced plastics.

Pumps and Filter

Pumps are crucial to the working of OTEC plants. Therefore, heavy-duty marine pumps capable of pushing large volume per second (about 4 M3/s) of water are required. It is desirable to invest more on pumps of high efficiencies, this implies that could-water pipes could be of smaller diameters. Hence a reduction in the cost of building them. For an average commercial OTEC plant, the cost of the pumps constitutes about 10 or 15 per cent of the total cost of the plant.

Filters or sieves must be installed on the pipes so as to avoid debris, weed and other marine organisms entering into the system. Unwanted objects could easily damage the plant.

Submarine electric cable

Submarine electric cable is a key feature of OTEC plant. All the electric energy produced is transmitted from the plant to shore. The cables are deployed as deep as 1000 meters in the ocean. And are laid tens of kilometres into the land where the power is used. Because these cables have to be long and need to be connected to a platform that may not be stationary, they need to be flexible. They also need to withstand sea conditions for many years.

For OTEC plants cited at about 30 Km or less away from land, for instance, in the Bight of Benin in Nigeria, power (Alternating current) can be transmitted effectively without losses. But for sites beyond 30 Km the power must be utilised on site for the production hydrogen. But to transmit the power to the main land for instance, the Oshogbo National Control Centre, the power (AC) has to be converted to direct current (DC). But because of energy lost during transmission, in this way the distance must not exceed 400 Km. In case of Nigeria, the transmission distance is much less.

Energy losses due to cable transmission is not a serious problem. It is small and common to conventional electricity stations. The loss is usually not more than one to there percent.

Heat Exchangers

Other most crucial components of OTEC plant are the heat exchanger. The efficiency of OTEC operation largely depends on the heat exchangers. A typical plant has two, on in the evaporator and one in the condenser. Their performance is extremely important since they must transfer as much heat as possible from the warm water to the working fluid (for example, ammonia) in the evaporator and as much as possible out of the working fluid back into the could water at the condenser in order to maintain the greatest possible temperature within the cycle. (Ford et al., 1987 P69). Theoretically, the requirement is that the heat exchangers must transfer heat absolutely. That is to say, the heat transfer from water to the working fluid equals the actual temperature difference between warm and cold sea water (20Cor 22C or more). Thus, there is need to use the most efficient heat exchanger so as to achieve maximum yields of the OTEC plant.

Through the ages techniques to perfect the heat transfer have been studied. First of all, the design is centred around the surface area of contact between the heat exchanger and the two fluids, namely seawater and ammonia. Page shows various types of heat exchangers that can provide high surface area to volume ratios. Again to achieve higher heat transfer coefficients, the fluid flow in the exchangers should be slow and even along the exchange surface. And the use of a technique referred to as enhancement, which is employed to increase the effective surface area of the parts of the exchanger. This is achieved by roughing the surface so that at microscopic level the ridges and furrows of effective surface area of exchange. Alternatively, this can be achieved by coating the effective surface area of the heat exchanger with a porous, thermally conducting materials, the internal structure of which provides the increase in surface area (Ford et al., 1987, p.70). Secondly, the surface area of contact must be maintained clean. Heat exchangers usually accumulate micro-organism that act as an insulator, thereby ruining the heat exchange properties of the components. Heat exchangers could be cleaned either mechanically, with a special brush or using chemicals that are not harmful to the environment.

In practice heat exchangers are not made from any metal. Some metals that are found to be suitable for OTEC plants are stainless steels, cupro-nickels alloys, titanium, aluminium. The choice of the metal to use depends on the type of working fluid also. For example ammonia reacts with cupro-nickels alloy, therefore it is not suitable. But it is alright with other fluids. Titanium is so expensive to use for OTEC that requires very very huge huge heat exchangers.

Perhaps the best choice of heat exchanger material is aluminium with ammonia as the working fluid. Aluminium is cheaply abundant in Nigeria,. Nigeria is one of the exporters of the metal.

The technical problems of OTEC technology lies squarely on the platform, cold water pipe pumps, cables and heat exchangers. The problems associated with these are being solved through time by scientist around the globe. Therefore, OTEC plants and other ocean energy systems would soon be a great challenge to nuclear plants and the rest of non-renewable energy systems. Among the three important ocean energy recovery systems, tidal, wave and OTEC, the latter is the only one that can be harnessed in negeria, due to some natural constraints such as low tidal and small size of waves in Nigeria waters.

4.9 BENEFITS OF OTEC

According to the national renewable energy laboratory of Hawaii, the benefits of OTEC plants are many and cant be categorised into economic and no-economic benefits. OTEC' economic benefits include these:

Helps produce fuels such as hydrogen, ammonia and methanol

Produces base load electrical energy

Produces desalinated water for industrial, agricultural, and residential uses.

Is a resource for on-shore and near-shore mariculture operations

Provides air conditioning for buildings

Provides moderate temperature refrigeration

Has significant potential to provide clean, cost –effective electricity for future

OTEC' non- economic benefits, which help us to achieve global environmental goals, include these:

Promotes competitiveness and international trade

Enhances energy independence and energy security

Promotes international socio-political stability
Has potentials to mitigate greenhouse gas emissions resulting from burning of fossil fuels.

The benefits of OTEC are great. However, no system is a hundred percent perfect. OTEC plants has some disadvantages which less than the benefits. The disadvantages (OTEC in Hawaii, 1999) are:

OTEC-produced electricity at present would cost more than electricity generated form fossil fuel at their current costs. The electricity cost could be reduced significantly if the plant operated without major overhaul for 30 years or more, but there are no data on possible plant life cycles.

OTEC plants must be located where the temperature of the ocean of about 1000 m is 40F or 4.4C through the year round. Ocean depths must be available fairly close to shore-based facilities for economic operations. Floating plant ships could provide more flexibility.

Although extensive and successful testing of OTEC has occurred in experiments on component part or small scale plants, a pilot or demonstration plant of commercial size needs to be built to further document economic feasibility for the country concerned.

Construction of OTEC plants and laying of pipes in coastal waters may cause localised damage to reefs and near-shore marine ecosystems.

Some additional development of key components is essential to the success of future OTEC plants, for example, less-costly large diameter, deep sea water pipelines, low pressure turbines and condensers for open-cycle systems, and so on.

4.10

SPECIFIC APPLICATIONS OF OTEC SYSTEMS

The primary aim of developing OTEC systems is to produce electricity. But as stated under section 4.9, OTEC systems have many applications, for example it can be used to desalinated water, support deep water mariculture, and provide refrigeration and air conditioning as well as and in crop growth and mineral extraction. These complementary products make OTEC systems even more attractive. Industrialists and some tropical countries like Nigeria can apply OTEC technology even if the price of oil remains low or if the country concerned have oil deposits. A brief explanation on the applications of OTEC systems is hereby given:

Deep-water-supported Mariculture

The cold seawater used in OTEC plants is full of nutrients and almost free of pathogens. It can be used to grow phytoplankton and microalgae on which fish and shellfish can be farmed commercially. This technique have been successfully used to grow salmon, trout, northern lobsters, oysters, stc. At the natural energy laboratory of Hawaii. (NELHA)

Since the discharged water from OTEC is free from pathogens other marine life thrives and populate in wherever the water flows. This could be beneficial to the local communities in the vicinity of OTEC plants.

Production of desalinated water

A mega-city such as Lagos, Nigeria, with a population of about 10 million, can benefit from OTEC for the supply of desalinated water. Desalinated water is produced in large quantities during the operation of open- or hybrid-cycle OTEC plants. To achieve this surface condensers are used, the condensate or desalinated water is freed of its salt and all impurities and can be used as natural freshwater. A small OTEC plant of 1MW capacity can produce about 4,300 cubic metres of desalinated water per day (National Renewable Energy laboratory, 1999)

Refrigeration and Air-conditioning

The cold seawater used in OTEC systems is near freezing – 5C. If this is run through pipes, it can be utilized to provide cooling to operations that are related or those that are near to the plant. The could water can also be used in chilled-water coils to provide air-conditioning for buildings refrigeration and air-conditioning is a necessity in Lagos and other coastal cities of Nigeria where temperature and humidity are unbearable.

Mineral extraction

Water is a universal solvent. It has the ability to gradually dissolve a lot of element. It has been estimated that there are 57 elements dissolved in water. Therefore, theoritically all the dissolved elements, especially uranium and other valuable ones, can be extracted from the seawater itself. Ocean-energy technology solves a fraction of the problem of mineral extraction from seawater, by pumping the water, economically to where the extraction could take place.

Further research into material sciences would one day yield fruitful results in the area of mineral extraction using processes that employ ocean energy (National Renewable Energy Laboratory, 1999).

4.11 cost and financing of OTEC Plant in Nigeria

The cost of the proposed OTEC plant in Nigeria is not the object of this dissertation. Nevertheless, it can be mentioned that the cost is simply the capital cost of construction and operation. The OTEC’s raw material is just seawater. This is free of charge. The cost of commercial OTEC plant is usually drawn from small OTEC plants already built. Therefore, the actual cost is a mere estimate based on a number of technical and economic factors that are cumbersome. At any rate, the cost is comparable to that of nuclear or hydro plants. But the cost of OTEC electricity could be up to two or four times higher than fossil or nuclear-generated electricity (Ford et al., 1987, p. 75)

The cost of an OTEC plant is affordable by Nigeria. Because Nigeria could afford to build three hydro and fire thermal stations. For example the Delta thermal station cost a total of nine billion Naira 1985 (Delta Power Station). Thus, Nigeria is expected to finance the proposed OTEC plant since there are no private electricity station in the country.

Electricity, especially for non-industrial use has been highly subsidised by the government. This is one of the reasons why the cost is not so important here. Furthermore, OTEC system operates from a non-renewable energy source – the ocean.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

Electricity is being generated by simply turning an electric generator or a turbine. The traditional means of turning the turbine are wind, nuclear, hydro or natural gas. In Nigeria only hydro and natural gas are being used. Their use has not been satisfactory. And even if they are, they are not renewable. Both may fall short or even finish one day. This calls for the need to search for a renewable source of energy that is more or less permanent. Hence the reason why ocean energy has been suggested as an alternative or additional source of electricity for the country.

The most modern method to produce electricity is the use of the oceans. Coastal states like Nigeria can use the most suitable ocean energy systems for their electricity needs. The best option for Nigeria is ocean thermal energy conversion (OTEC) – because of Nigeria's position on the globe.

Because of the difficulties in acquiring financial data, the cost of building OTEC plant is tactfully skipped. Nigeria has the wherewithal to finance such a project when the need arises.

Ocean energy systems are becoming cheaper and commercially more viable because of their prospects and the keen interest of the advanced countries that posses the technical know how to build them. The few plants and the prototypes built around the world yielded promising results. Every day brings ocean energy systems closer to reality.

When and wherever the traditional methods of producing electricity failed, the abundant energy of the oceans should be tapped. Thus, the ocean (or more precisely OTEC) can be an additional or an alternative energy of the twenty-first century, for Nigeria.

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