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Ocean energy - A sustainable approach to mitigate climate change

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ABSTRACT

Ocean Energy (OE) involves the generation of electricity from the waves, the tides, the currents, the salinity gradient, and the thermal gradient of the sea or the ocean. The ocean is an enormous and predictable source of renewable energy with the potential to satisfy an important percentage of the worldwide electricity supply. The oceans cover 75 per cent of the world surface and, therefore, it represents one of the largest renewable energy sources available to contribute to the security of energy supply and reduce greenhouse gases emissions. Globally, the theoretical potential of OE has been estimated by the International Energy Agency's Implementing Agreement on Ocean Energy (IEA-OES) between 20,000 and 90,000 TWh/year (as a reference, the world's electricity consumption is around 16,000 TWh/year). This breaks up depending on technology, in the following way: tide and marine current resources represent estimated annual global potentials exceeding 300 TWh and 800 TWh per annum, respectively. Wave energy has an estimated theoretical potential of between 8,000 TWh and 80,000 TWh per annum. The theoretical potential of ocean thermal gradient (also known as OTEC) is estimated around 10,000 TWh per annum. The potential of salinity gradients is estimated at 2,000 TWh per annum. The paper deals each and every component of ocean energy and its potential in India.

Key words : Ocean energy, Salinity gradient, Thermal gradient, Wave energy, Renewable energy

INTRODUCTION

Energy drives the global economy. Global consumption of energy is growing at an astonishing rate. The US Department of Energy projects an increase of 60% in worldwide total energy consumption from 1999 to 2020. Accompanying this forecast is a 20-year increase in carbon dioxide emissions (60% increase above 1999 levels) as the world's population increases from 6.0 to 7.5 billion people. While the United States with 5 per cent of the world's population generates 30 per cent of the world GDP, consumes 25 per cent of the world's energy and emits 25 per cent of the world's CO_2, it is believed the developing countries with their thirst for energy will drive the energy demand over the next two decades. Developing countries are projected to increase energy consumption by 3.8 per cent per annum. Adjustment of this projection to a more realistic level of 2 per cent per annum is the consensus among energy industry analysts. The major source for low-cost, convenient energy globally is fossil fuels and fossil fuels will continue to be the major source of energy for the foreseeable future. Renewable energy use while expected to rise 53 per cent during the period 1999 to 2020.

The current energy production is largely based on fossil fuels and is not only characterized by (i) vulnerability and (ii) imminent scarcity, but also by (iii) the emission of greenhouse gasses as a consequence of the combustion of fuels. It is very probable that this human fossil-fuel burning is the biggest contributor to climate change. Each of these three concerns should provide enough motivation for drastically reducing the burning of fossil fuels. This should be done by reducing the energy demand (consumption) and by changing the energy supply (sources and production). In order to meet the respective concerns, the energy supply should be based on locally available alternative energy source, renewable energy source, and environmental-friendly non-combustion energy conversion.

Unlike other renewable energy sources (RES), Ocean Energy (sometimes also referred as Blue Energy) is not captured from a single source, but, instead, is stored in a variety of forms: the energy of waves, the kinetic energy of marine and tidal currents, the potential energy of tides, and salinity or thermal gradients. As a consequence of this variety the number of concepts for ocean energy conversion is very large. A first, basic division is grounded on the specific source of energy that the technology is tapping into: waves, tides, currents, salinity gradient and thermal gradient.

The importance of the renewable energy as the clear, cheap and salubrious with environmental is clearly obvious. The renewable energy sources are being derived from ocean include: tidal power, wave power, ocean

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thermal energy conversion, ocean currents, ocean winds and salinity gradients. The tidal power, wave power and ocean thermal energy conversion has been well-developed. Ocean thermal energy conversion is the extracting energy with using a heat engine. These sources of energy may exist in sites with large temperature differences. The salinity gradient energy is achievable in places that a solution flow with a specific salinity concentration runs into other solution with different salinity concentration. The best application of this source of energy when the low salinity flows of water (river water) mixing with saline water (see water) so the main factor in salinity gradient energy is the “difference of chemical potential” between the diluted and concentrated solutions. There are one estimate that shows the total discharge of global rivers is 1.3 × 106 m^3/s (Kuleszo, 2008). Therefore the global potential of salinity gradient of power is 2.8 TW this amount is near to 2.6 TW that estimated in 1977 by Wick and Schmitt (1997). According to studies (*www.eia.doe.gov*) in 2008 about the average world energy consumption, this amount of energy is more than the global electricity consumption Veerman *et al.* (2011).

In above mentioned, every wave its own objectives, specification, needs and advantages and disadvantages. The paper deals all components of OE/BE with its objective, specification and potential in India.

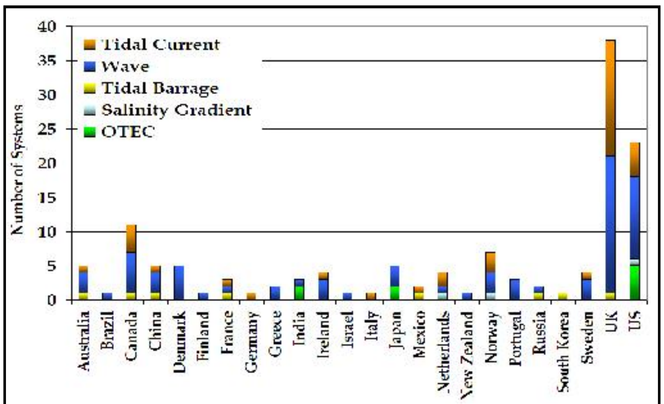

Fig. 1 : Ocean energy-related research, demonstration and commercial activities, as of December 2007 on entire globe. Information courtesy of Powertech Labs, Canada

Wave energy :

Wave energy converters (WECs) capture the energy found in ocean surface waves. These waves result from the action of wind blowing over long stretches (or fetches) of open ocean surface. Like wind power the availability of wave power is variable and will depend on the prevailing wave conditions at any particular time, sometimes producing maximum power and sometime producing none. Wave power systems convert the motion of the waves into usable mechanical energy which in lump can be used to generate electricity.

Five years ago, especially in Europe, the sector experienced a resurgent interest. Today, wave energy conversion is being investigated in a number of EU countries; major activity is also ongoing outside Europe, mainly in Canada, China, India, Japan, Russia, and the USA.

Wave energy potential :

The global wave power resource in deep water (*i.e.* 100 m or more) is estimated to be ~ 110 TW (Panicker, 1976). The economically exploitable resource varies from 140-750 TWh/y for current designs of devices when fully mature (Wavenet, 2003) and could rise as high as 2,000 TWh/y (Thorpe, 1999), if the potential improvements to existing devices are realised. Global electricity consumption is about 15,400 TWh/y (BP, IEA), hence wave could supply up to 13 per cent of current world electricity consumption which is equivalent to about 70 per cent of what is currently supplies by hydroelectric schemes.

Cost :

The predicted electricity generating costs from wave energy converters have shown a significant improvement in the last 20 years, which has reached an average price below 10 c€/kWh. Compared to e.g. the average electricity price in the EU, which is approx. 4 c€/kWh, the electricity price produced from wave is still high, but it is forecasted to decrease further with the development of the technologies.

Potential of wave energy in India :

In India the research and development activity for exploring wave energy started at the Ocean Engineering Centre, Indian Institute of Technology, Madras in 1982. Primary estimates indicate that the annual wave energy potential along the Indian coast is between 5 MW to 15 MW per meter, thus a theoretical potential for a coast line of nearly 6000 KW works out to 40000-60000 MW approximately. However, the realistic and economical potential is likely to be considerably less. There is also a project running at Thiruruvananthpuram, Vizhinjam Fisheries Harbor, which capacity is around 150 Kw.

Barriers :

– Depends on the waves – variable energy supply
– Needs a suitable site, where waves are consistently strong.
– Visual impact if above water or on shore.

– Poses a possible threat to navigation from collisions due to the low profile of the wave energy devices above the water, making them undetectable either by direct sighting or by radar.
– May interfere with mooring and anchorage lines with commercial and sport-fishing.
– May degrade scenic ocean front views from wave energy devices located near or on the shore.

Tidal energy :

Tidal energy conversion techniques exploit the natural rise and fall of the level of the oceans and of the seas caused principally by the interaction of the gravitational fields in the Earth-Sun-Moon system. Some coastlines, particularly estuaries, accentuate this effect creating tidal ranges of upto ~17 m.

The vertical water movements associated with the rise and fall of the body of water, and horizontal water motions (tidal currents), accompany the tides. These resources therefore have to be distinguished between tidal range energy (the potential energy from the difference in height between high and low tides) and tidal current energy (the horizontal movement,*i.e.* the kinetic energy of the water in a tidal current).

Tidal range energy :

Potential energy associated with tides can be harnessed by building barrages or other forms of engineering constructions across an estuary. Tidal barrages consist of a large, dam-like structure built across the mouth of a bay or an estuary in an area with a large tidal range. As the level of the water changes with the tides, a difference in height develops across the barrage. Water is allowed to flow through the barrage via turbines, which can provide power during the ebb tide (receding), flood tide (allowing water to fill the reservoir via sluice gates), or during both tides. This generation cycle means that, depending on the site, power can be delivered twice or four times per day on a highly predictable basis.

Tidal range energy potential :

The global tidal range energy potential is estimated to be about 200 TWh/y, about 1 TW being available at comparable shallow waters. Within the European Union, France and the UK have sufficiently high tidal ranges of over 10 metres. Beyond the EU, Canada, the CIS, Argentina, Western Australia and Korea have potentially interesting sites. At present 3 tidal barrages operate as commercial power plants, amounting to a worldwide total of 260 MW of installed capacity.

Tidal range energy cost :

Tidal range energy projects require normally higher capital investment at the outset, having relatively long construction periods and long payback periods. Consequently, the electricity cost is highly sensitive to the discount rate used. In terms of long term costs, once the construction of the barrage is complete, there are very small maintenance and running costs and the turbines only need replacing once around every 30 years. The life of the plant is indefinite and for its entire life it will receive free fuel from the tide.

Tidal currents :

Rather than using a dam structure, tidal current devices are placed directly "in-stream" and generate energy from the low of the tidal current. There are a number of different technologies for extracting energy from tidal currents. Many are similar to those used for wind energy conversion, *i.e.* turbines of horizontal or vertical axis ("cross flow" turbine, as well as others such as, venturis and oscillating foils). Additionally, there are a variety of methods for fixing tidal current devices in place, including seabed anchoring, via a gravity base or driven piles, as well as floating or semi-floating platforms fixed to the sea-bottom via mooring lines.

In contrast to atmospheric airflows, the availability of tidal currents can be predicted very accurately, as their motion will be tuned with the local tidal conditions. Because the density of water is some 850 times higher than that of air, the power intensity in water currents is significantly higher than in airflows. Consequently, a water current turbine can be built considerably smaller than an equivalent powered wind turbine.

Tidal currents potential :

The global tidal current energy resource is very large. Countries with an exceptionally high resource in tidal or current energy include the UK (E&PDC, 1993), Ireland, Italy, Philippines, Japan and parts of the United States.

Tidal currents cost :

Marine current energy is one of the most promising new renewable energy sources. The know-how is available to combine existing technologies. Marine currents have the potential to supply significant quantities of energy into the grid systems of many countries. As interest grows, marine current energy is likely to play an increasing role in complementing other energy technologies and contributing to the future global energy supply mix.

Potential of tidal energy in India :

Since India is surrounded by sea on three sides, its potential to harness tidal energy is much better. The most attractive locations are the Gulf of Cambay and the Gulf of Kachchh on the west coast where the maximum tidal range is 11 m and 8 m with average tidal range of 6.77 m and 5.23 m, respectively. The Ganges Delta in the Sunderbans in West Bengal also has good locations for small scale tidal power development. The maximum tidal range in Sunderbans is approximately 5 m with an average tidal range of 2.97 m.

The identified economic tidal power potential in India is of the order of 8000-9000 MW with about 7000 MW in the Gulf of Cambay about 1200 MW in the Gulf of Kachchh and less than 100 MW in Sundarbans.

Proposed tidal power projects in India :

Kachchh tidal power project :

In, 1970, the CEA had identified this tidal project in the Gulf of Kachchh in Gujarat. The investigations were formally launched in 1982. Sea bed analysis and studies for preparation of feasibility report were of highly specialized and complex nature without precedence in the country. More than twelve specialized organizations of Government of India and Government of Gujarat were involved in the field of investigations. The techno-economic feasibility study has been completed in a very scientific and systematic manner and the feasibility report completed in 1988.

The proposed tidal power scheme envisages an installation of 900 MW project biggest in the world, located in the Hansthal Creek, 25 kms. from Kandla Port in Distt. Kachchh of Gujarat State. It comprises of the following:

The main tidal rockfill barrage of 3.25 km length was proposed to be constructed across Hansthal Creek which will accommodate the power house, sluice gates and navigational lock.

It envisages installation of 900 MW capacity comprising of 36 geared bulb type turbo-generators units of 25 MW each and 48 sluice gates each of 10 M x 12 M size would generate 1690 Gwh of energy annually. Unfortunately, this project execution has not been taken up so far because of unknown reasons.

Durgaduani creek :

The country's first tidal power generation project is coming up at Durgaduani Creek of the Sundarbans. The 3.75 mw capacity Durgaduani Creek tidal energy project is a technology demonstration project and will span over an area of 4.5 km. (Oct., 2008 data).

Tidal barriers problems faced in exploiting tidal energy :

– Intermittent supply - Cost and environmental problems, particularly barrage systems are less attractive than some other forms of renewable energy.
– Cost - The disadvantages of using tidal and wave energy must be considered before jumping to conclusion that this renewable, clean resource is the answer to all our problems. The main detriment is the cost of those plants.
– The altering of the ecosystem at the bay - Damages like reduced flushing, winter icing and erosion can change the vegetation of the area and disrupt the balance.
– Only provides power for around 10 hours each day, when the tide is actually moving in or out.
– Limited construction locations and expensive to construct.
– Barrages may block outlets to open water. Although locks can be installed, this is often a slow and expensive process.
– Barrages may affect the tidal level - the change in tidal level may affect navigation, recreation, cause flooding of the shoreline and affect local marine life.
– They can only be built on ocean coastlines, which mean that for communities which are far away from the sea, it's useless.

Salinity gradient power :

At the mouth of rivers where fresh water mixes with salt water, energy associated with the salinity gradient can be harnessed using pressure-retarded reverse osmosis process and associated conversion technologies. Another system is based on using freshwater upwelling through a turbine immersed in seawater, and one involving electrochemical reactions is also in development.

Significant research took place from 1975 to 1985 and gave various results regarding the economy of PRO and RED plants. It is important to note that small-scale investigations into salinity power production take place in other countries like Japan, Israel, and the United States. The principle of salinity gradient energy is the exploitation of the entropy of mixing freshwater with saltwater. This energy source is not easy to understand, as it is not directly sensed in nature in the form of heat, waterfalls, wind, waves, or radiation.

Salinity energy potential :

Salinity gradient power plants are based on the natural mixing of fresh and salt water (IEA, 2009). Collision of fresh and salt water provides large amounts of energy, which this technology aims to capture. Many areas exist where industrial users (such as sewage treatment plants) discharge substantial volumes of fresh or low-salinity water into the ocean; such locations could be ideal for implementing prototype salinity gradient systems.

Salinity power is one of the largest sources of renewable energy that is still not exploited. The potential energy is large, corresponding to 2.6 MW m^3/sec freshwater when mixed with seawater. The exploitable potential world-wide is estimated to be 2000 TWh/y. The potential cost of energy from this source is higher than most traditional hydropower, but is comparable to other forms of renewable energy that are already produced in full-scale plants.

Electricity generation through the use of salinity gradients between salt and fresh water is a relatively new concept. While discovered and discussed in the 1970s, research has been slow and most of it only recently. Two practical methods concerning membrane technology are currently being researched: the reverse electro dialysis (RED) method and pressure retarded osmosis (PRO). Both technologies are dependent on the semi permeable membrane. A semi-permeable membrane is selective in its permeability, *i.e.* only specific substances can pass through the membrane. Both processes rely on ion-specific membranes. The technology RED as well as PRO is in the research and development phase. The major obstacle is the cost of the membrane. Two countries, Norway and the Netherlands, are especially active in the R&D of osmotic power. In addition, the hydrocratic generator technology also relies on salinity gradients for energy generation.

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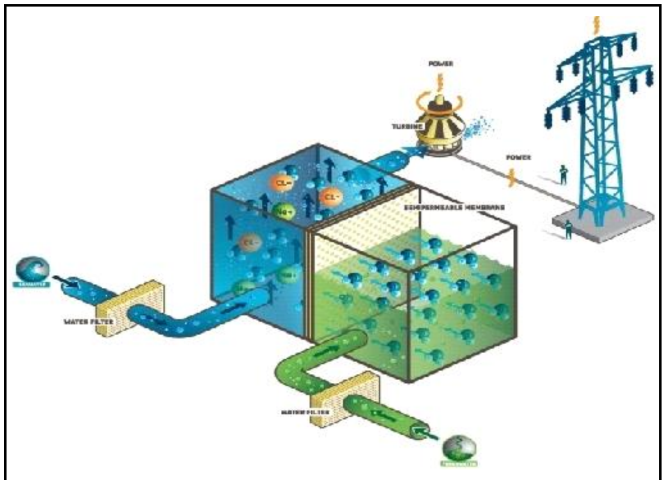

Fig. 2 : Method showing power generation through salinity gradient

Potential and status of salinity gradient :

The technology is still in its infancy, as illustrated in Fig. 1. The salinity gradient technologies are in their part-scale (tank) phase which means that the concepts and prototypes are undergoing tests in the laboratory environment (IEA, 2009). Clearly, the other ocean energy technologies have advanced further in the R&D process. However, the global potential of the technology of using the salinity gradient for energy is estimated to be around 2000 TWh/year (IEA, 2007, p.80).

Ocean thermal energy conversion :

The principle of ocean thermal energy conversion (OTEC), consisting in using the heat stored in the oceans to generate electricity, originated with a French physicist, Jacques D'Arsonval, in 1881. His pupil, Georges Claude, built the first plant at Matanzas Bay, Cuba in 1930, with a gross output of up to 22 kilowatts. The United States became involved in OTEC research in 1974, when the Natural Energy Laboratory of Hawaiii Authority was established. The Laboratory has become one of the world's leading test facilities for OTEC technology. Japan also continues to fund research and development in OTEC technology.

Table 1 : Comparison of the five basic forms of ocean energy. Source: IEA, 2007

Form of ocean energy	Estimated energy (TWh/year)	% of current global electricity production. Current production: 17 400 TWh (TWh/year)
Tides energy	300+	1.70%
Wave energy	8000-80000	46 % - 460 %
Tidal currents	800	4.60%
Thermal gradients	10 000	57.50%
Salinity gradients	2000	11.50%

Due to solar heating, the top layer of the water is much warmer than deep ocean water. Where the temperature difference between the warmer, top layer of the ocean and the colder, deep ocean water is about 20°C (36°F), the conditions for OTEC are most favourable. These conditions exist mainly in coastal areas located close to the Equator. The amount of energy available in the temperature gradient between hot and cold seawater can be substantially larger than the energy required to pump the cold seawater up from the lower layers of the ocean. To convert this thermal gradient into electrical energy, the warm water can be used to heat and vaporize a liquid (known as a working fluid). The working fluid develops pressure as it is caused to evaporate. This expanding vapour runs through a turbine generator and is then condensed back into a liquid by cold water brought up from depth, and the cycle is repeated. Some energy experts claim that once it reaches cost-competitiveness with conventional power technologies, OTEC could produce billions of watts of electrical power.

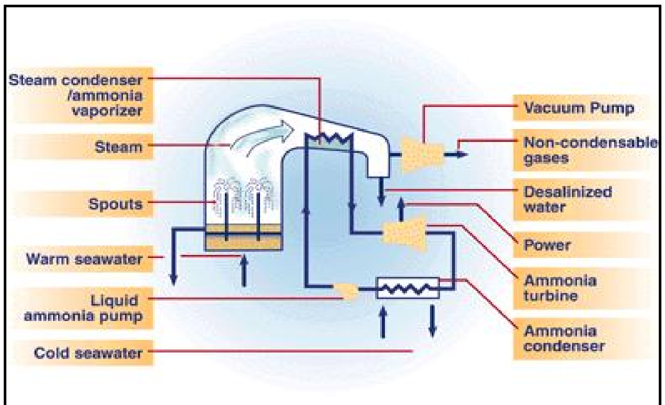

Fig. 3 : Method showing power generation through salinity gradient

Ocean thermal energy potential :

The world's largest solar collector absorbs a tremendous amount of the sun's energy, averaging about 65 million gigawatts (a gigawatt is one million kilowatts), or 570 quadrillion kWh/y - more than 5,000 times the amount of energy used in all forms by humans on the planet. A typical square mile of that collector - otherwise known as the surface waters of the Earth's vast oceans - absorbs an average of about 500 MW, or annually more energy than the equivalent of 2.6 million barrels of oil. The estimated global resource is 10,000 TWh/y.

Ocean thermal energy potential :

OTEC has a potential installed capacity of 180,000 MW in India.

Barriers :

– OTEC-produced electricity at present would cost more than electricity generated from fossil fuels at their current costs.
– OTEC plants must be located where a difference of about 40 degrees Fahrenheit occurs year round.
– Ocean depths must be available fairly close to shore-based facilities for economic operation.
– Construction of OTEC plants and laying pipes in coastal waters may cause localized damage to reefs and near-shore marine ecosystems.

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