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Generation of Electricity by Osmosis

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Abstract : In nature there are types of energy sources are available some of them are Renewable and Non-Renewable Energy Sources, but we can't continue using several of our energy sources from where we gain energy today. As we know that energy neither be created nor be destroyed but it convert it one form of energy to another form of energy hence it's necessary that to find an energy source that can be Green and Clean energy source.
Osmotic power provides excellent environmental performance and CO_2 free power production will qualify for green certificates and other supportive policy measures for renewable energy. The estimated energy cost is comparable and competitive with the other renewable energy sources. For both the commercial power companies and technology suppliers Osmotic Power represent an attractive new business potential.
The paper includes how to generate electricity by using Osmotic Energy. Some of the methods includes PRO (Pressure Retarded Osmosis), Reverse Electro Dialysis(EDR)- Capacitive Deionization(CD) which would generally require two water bodies of different concentration like estuaries, lakes and ponds. Our country is blessed with 7000km of coastline and many rivers and its distributaries thus we have potential to generate electricity especially to populous cities like Mumbai, Chennai.
Keywords : Pressure Retarded Osmosis, Reverse Electro Dialysis.

1.Background

Whenever we consider the renewable forms of energy, we mostly consider the energy produced from the Solar and wind. However these forms of energy can be unreliable as it is specific to the climatic and the seasonal changes. The one of the promising new field of renewable energy source is Salinity Gradient Energy. In 1954 Pattle(early Pioneer of PRO) wrote: The osmotic pressure of sea-water is about 20 atmospheres, so that when a river mixes with the sea, free energy equal to that obtainable from a waterfall 680 ft high is lost. This 'salinity power' is in principle clean and sustainable and gives no thermal pollutionand no CO2 exhaust.The global energy output from estuaries is estimated at2.6TW , which represents approximately 20% of the presentworldwide energy demand. Large amounts of blue energy canalso be made available from natural or industrial salt brines.In the literature, several techniquesfor energy conversion of the salinity gradient have beenproposed: pressure-retarded osmosis, reverse electrodialysis and vapor-pressure difference utilization. Although thepotential for salinity-gradient energy was recognized more thanhalf a century ago, until now utilization has been consideredto be neither economically feasible nor technically attractivewhen compared to fossil fuel systems. Here we would try to get the overview of Pressure retarded osmosis and Reverse ElectroDialysis.

2. Pressure Retarded Osmosis

2.1Introduction

PRO is based on the concept of forward osmosis between two liquids with different concentration, which are placed side by side, separated by a semi permeable membrane only. The semi permeable membrane allows solvent molecules, which are generally smaller in diameter, to move across it but retards diffusion of solute molecules. This movement consumes no energy. In a generic model of PRO electric generator, solvent used is water and solute is mainly sodium chloride or salt in layman's term. The existing concentration gradient between them causes solvent to diffuse from less concentrated region to more concentrated region across semi permeable membrane. The diffusion process increases the relative energy density of the solvent in the more concentrated solution. Thus, intense osmotic pressure is created in it. This pressure, calculated based on the concentration gradient of fresh water and sea water, can go up to 25 bars, which is roughly equivalent to potential energy of a column of water stored 270 meters above ground level. The pressure created can then be used to turn the turbine to generate electricity. Currently, PRO is still new in renewable power generation technology and is expected to have a great future. It has an advantage over other alternative power sources such as wind and solar power generators whereby PRO can be used throughout the day and in any place as long as there is water supply. It is noteworthy that PRO generates clean power with no harmful emission. Abundant of water resource makes PRO to have better reliability and lower cost. Its flexibility, in terms of size and input sources, makes PRO scalable and can be tailor made to generate sufficient electricity required. A small scale model would be an excellent power source for isolated telecommunication base transceiver towers and buildings in remote areas unreachable by national power grid.

2.1Membranes

By reflecting the PRO applications, high salt rejection and high water permeability are the key parameters on the membrane developments on PRO. Until the early 2000s, research on the flat-sheet membranes predominantly focused on two materials: cellulose acetate (CA) membranes developed by Loeb in the 1960s, and commercialized cellulose triacetate (CTA) membranes developed and provided by Hydration Technology Innovation (HTI). From the beginning of 2010, thin-film composite (TFC) flat-sheet membranes, mostly composed of two layers (a polyamide (PA) active layer and a highly porous support layer), are actively being developed due to their advantage on the PRO performance, as compared to a CTA commercial membrane. Compared to the CTA membrane, TFC membranes have a relatively higher salt retention rate due to their thin-film PA selective layer while also having a lower Internal Concentration Polarization (ICP) phenomenon, which leads to a higher water flux because of the higher porosity in the supportlayer. Several research groups in the US and in Singapore have taken leadership positions in developing flat-sheet membranes.

2.3 Plant Designs

Several plant designs have been developed for PRO powergeneration.

A. Sea Level PRO Power Plant

Freshwater is taken from a river close to its outlet. Seawater is fed into the plant by underground pipes. The brackish water is let to the naturalbrackish water zone of the estuary thus maintaining theflow of water in the river. In many respects this PRO process can be designed as a run-of-river hydropowerplant.

B. Sub-Sea PRO Power Plant

Another major concept utilizes the gravity instead ofthe pressure exchanger to pressurize the incomingseawater. By placing the whole plant 100 to 130 metres below sea level the efficiency of the process can beincreased significantly. The concept comprises a normal hydropower plant runningon water from a river or a lake utilizing the extra waterhead. A membrane plant pumps the water out of the subsea cavern.

C. PRO Power Plant Below The Sea Level

Osmotic power can also be used for pumping of wateracross dikes, for example from IJsselmeer in the Netherlands to the North Sea. The flexible design of the PRO plant allows the combined power and pumpingstation (yellow) to be fitted between existing infrastructures as the illustration to the left suggests. The membranesection can preferably be located slightly below ground.Filtration units for saltwater and freshwater as well as turbine halls can be placed on appropriate locations in thearea. This concept produces power at the same time as itdrains the dyke. An additional advantage is that the water going into the ocean will be cleaner than the unprocessedfreshwater.

2.4Applications

1. Stand-Alone PRO Processes

A Norwegian power company (Statkraft) that has specialized in hydro power analyzed the economic feasibility of a salinity gradient power in 2008. Since then, international interests have been drawn to PRO and Statkraft led technological developments in the field. The world's first PRO pilot plant prototype was constructed by Statkraft in Tofte, aiming at producing 10 kW of electricity by pairing river water as a feed solution and seawater as a draw solution. Spiral-wound membrane modules which adopt an effective membrane area of 2000 m2 and 10–15 bars of the hydraulic pressure were applied, resulting in an average power density of 3 W/m2. Unfortunately, this value was relatively lower than the power density of 5 W/m2 required to make PRO economically feasible Statkraft announced the termination of the PRO pilot project at the end of 2012, ahead of the construction of the scaled-up pilot plant (2 MW). This is shown in Fig.1.

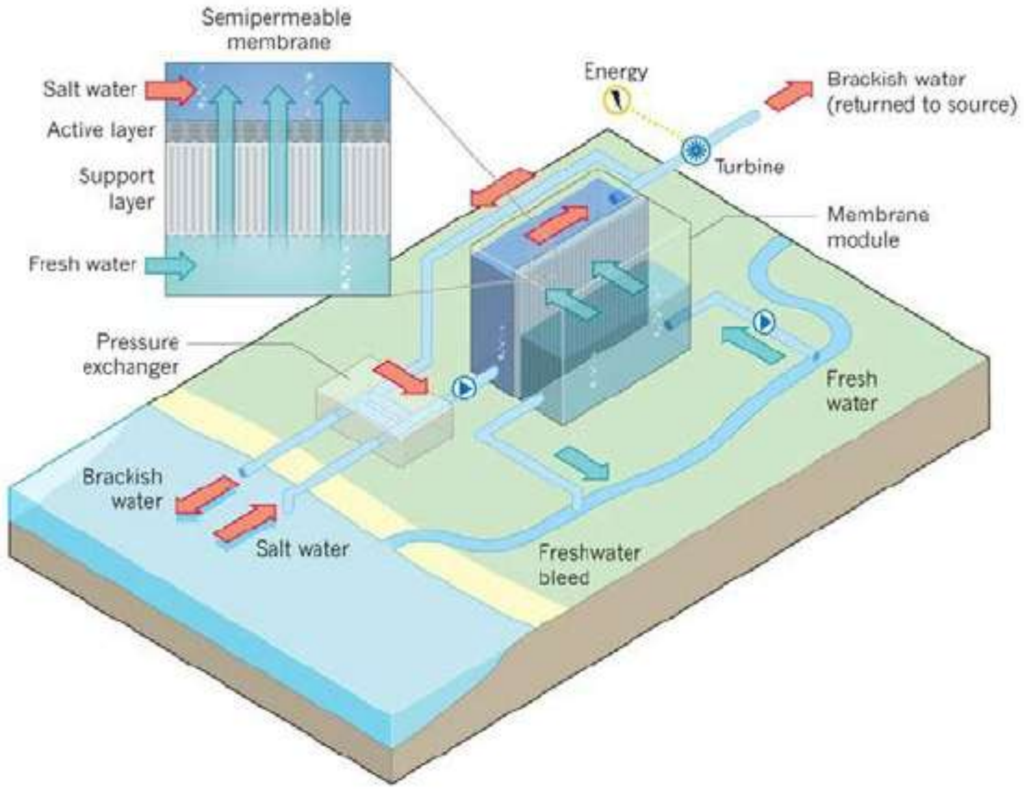

Fig.1

2. PRO-Hybrid Processes

The primary drawback of a stand-alone PRO process is its relatively low power generation, resulting from the low osmotic pressure difference between seawater and river water. If the required energy for pre-treatments are taken into account, the net energy can be further decreased. Based on these considerations, the hybridization of the PRO process with other desalination technologies has actively been investigated. In particular, the RO process is the most preferred option to be coupled with because of advantages such as the alleviation of environmental issues caused by the direct discharge of concentrated brine from RO into the ocean and increasing the PRO power generation by utilizing the high-concentrated brine as a draw solution

A prototype RO-PRO hybrid plant was first constructed in Fukuoka (Japan), as part of the national project named the "Mega-ton Water System". The plant was originally designed by combining RO, PRO, and sewage treatment systems. By utilizing 420 m3/d of the wastewater effluent as a feed solution and 460 m3/d of the RO brine as a draw solution, the eight 10-inch hollow-fiber membrane modules from Toyobo were achieved with the maximum power density of 13 W/m2 at 30 bar of the hydraulic pressure . A scale-up of this RO-PRO hybrid plant is currently being planned in Japan. Another pilot-scale PRO-hybrid research project has been conducted as the "Global MVP" project in Korea. The objective of this project was to evaluate the feasibility of the RO-MD-PRO hybrid process in terms of reducing the discharged water concentration and the energy consumption. In the hybrid process, the concentrated RO brine enters the MD feed side, and the further concentrated MD brine is then utilized as a PRO draw solution while the waste water effluent is used as the feed solution

Consequently, improvement of total plant efficiency compared to a stand-alone RO plant is expected due to the additional water production by MD and the reduction of net energy consumption resulting from the PRO energy generation. Specifically, the following pilot plant will be built: a RO system capable of 1000 m3/d water production, a MD system with a water production capacity of 400 m3/d, and a PRO system having a 5 W/m2 power density. In the US, Achilli reported the experimental results of their RO-PRO small-pilot system, in which they demonstrated the possibility of a PX between the RO and PRO systems

Three 2.8 m2 spiral-wound RO membrane modules (SW30-2540, Dow Film Tec) and a 4.18 m2 4040 spiral-wound PRO membrane module developed by Oasys Water were installed. By applying filtered municipal tap water as the PRO feed solution and synthesized seawater as the RO feed water, the average power density of the RO-PRO hybrid system with the PX was reported to be 1.1–2.3 W/m2. This concept was further developed by Sarp*et al.* and Prante . Energy recovery rather than energy production was proposed in their works, obtained by employing the high-pressure diluted PRO draw solution to pressurize the RO feed water via the PX. Another approach, a closed-loop PRO process referred to as osmotic heat engine (OHE), has been proposed; it is composed of two steps: energy generation and draw solution recovery. The possibility of utilizing low-grade heat sources such as solar and geothermal energies and biomass heat to re-concentrate the draw solution via the thermal separation stage was regarded as the benefit of the OHE. Further challenges, however, remain before this becomes an economically feasible process. Enhancing the efficiency of the power generation can be achieved by selecting a draw solution that has a high osmotic pressure, high solubility, and high recovery using low-grade heat . Recently, a PRO-MD hybrid OHE system that uses methanol as an organic solvent was suggested in an attempt to improve the thermal separation efficiency of the draw solution.

3. Reverse Electro dialysis

The process of reverse electro dialysisgenerates a voltage from an ionic gradient separated by a semi permeable membrane, forminga concentration cell. Examples of ionic gradients are found in human cells [K+ channels], electric eels [electrocytes] and estuaries [river: ocean]. In the latter example,fresh water mixes with oceanwater naturally and becomes brackishwater, but this unobstructed diffusion can be harnessed into energy using reverseelectro dialysis. The difference in salinity between river water (low concentration of salt) and ocean water (highconcentration of salt) at an estuary can be separated with a semi]permeable membrane, resulting in a voltage defined by the difference in saline concentrations.

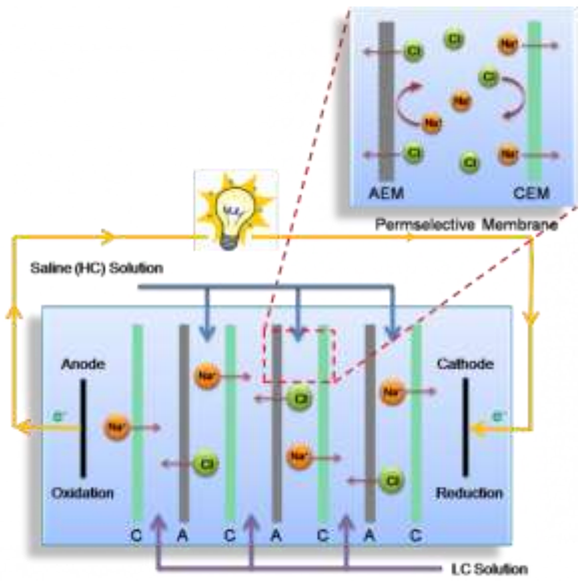

Fig. 2 Reverse Electrodialysis

The hybrid CDI(capacitive deionization)-RED system uses a single feed saline water to have freshwater and electric power. A CDI cell charged at constant voltage generates three different streams: fresh water stream, low salt concentrated stream, and high salt concentrated stream. Instead of disposing directly the CDI brine, it can be passed through the RED cell to produce energy. In this study we used 15, 000 ppm as a feed concentration to the hybrid CDI-RED system. More studies can be conducted at higher salinities such as at 40,000 ppm (seawater). Furthermore, extensive studies can be carried out using constant current in CDI cell as in so that the two hybrid systems, i.e., constant voltage driven CDI-RED and constant current driven CDI-RED can be compared in terms of performance. The overall capital cost and operational cost can be investigated to see the feasibility of commercializing the concept.

A cellpair, which is the basic repeating unit in RED, comprises one anion-exchange membrane, onecation-exchange membrane, one concentrated solution, and one dilute solution. Lacey derived hisown equation for calculation of voltage outputfrom a cell pair of a RED stack. Next he madecalculations to evaluate the influence of variableson power output from RED cells. He found relatively good results in the case of extremelylow membrane-to-membrane distance, equal to0.1 mm. For example, he found the net poweroutput at peak equal to ca. 10,000 mW/m2 (concentration of brine,1.45 N; thickness of brinecompartment, 1 mm; thickness of dilute compartment,0.1 mm; velocity of brine, 0.5 cm/s;velocity of dilute solution, 10.0 cm/s).

There project report of Danny Tate, estimated that 1m3 of salt water mixing with 1m3 of fresh water generated 0.74MJ of electricity. The solution was assumed to be ideal i.e. it had salinity gradient of ratio 1:50 and it was considered to be 100% efficient.

So based on the above estimate we calculated the electric energy that can be generated on the estuaries of India.

Table 2.

			Power Generated		
Sr.no	**Name Of river**	**Average Disharge(m3/s)**	**100% Efficiency (MW)**	**1% Efficiency(MW)**	**Sea**
1	Godavari	3505	2593.7	49.07	Bay Of Bengal
2	Krishna	2213	1637.6	16.376	Bay Of Bengal
3	Mahanadi	2119	1568	15.68	Bay Of Bengal
4	Narmada	1447	1070.78	10.707	Arabian Sea
5	Brahmi-Baitarna	903	668.22	6.68	Bay Of Bengal
6	Cauvery	677	500.98	5	Bay Of Bengal
7	Tapti	489	361.86	3.61	Arabian Sea
8	Subarnekha	392	290.08	2.9	Bay Of Bengal
9	Mahi	383	283.42	2.83	Arabian Sea
10	Penner	200.4	148.296	1.48	Bay Of Bengal
			9122.936	114.333	

Thus from the above table it can be concluded that the rivers can have potential from 114.3 MW to 9.33GW energy, which is of very large capacity of renewable energy source.

Conclusion

The processes are not new, but there was a significant lack of research in doing so. Recently, the European Union have decided to get their energy manufactured from the renewable sources of energy and has set the target to reduce the carbon emission by 100%.

It was only after Stakraft, this area was given importance for research. The basic hindrance for these process are:

1. The cost of membranes are very high to be manufactured.
2. The life of membranes are affected by the impurities present in water.
3. The cost of pre-treatment of feed is expensive, thus overall electricity generated is very expensive. Thus, its unable to compete with existing power sources.
4. However, this is better option for harnessing renewable energy since there are large number of continuously flowing rivers across the world.
5. The brine produced can be used to extract precious heavy metals or other chemicals.

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