

A Paper on Osmotic Power Plants

J. Ronald Aseer, Department of Mechanical Engineering,
Galgotias University, Yamuna Expressway
Greater Noida, Uttar Pradesh
Email ID: j.ronaldaseer@Galgotiasuniversity.edu.in

ABSTRACT: Pressure Retarded Osmosis (PRO) operating osmotic power plant is a promising technology for renewable-resource power generation. A wealth of literature on replacing traditional fossil fuel power plants has been published in PRO feasibility. Within this paper the PRO and the latest ground breaking Dual Stage PRO method are discussed briefly with the perspective of the writers on the potential growth and implementation of the PRO power plants. Osmotic power plants belong to renewable sources of ocean energy that harness the capacity of salinity gradients that occur in the mixing zone between river and sea water at the mouth between rivers. The global potential of salinity gradient energy is massive and technically restricted only by the flow of water into the oceans of the world's rivers. Just a small amount of the ability can be used in practice. Extractable river water is restricted to preserving the river's ecological integrity, and the ecological potential for osmotic power plants is added. Every river-mouth is a potential osmotic power plant location but there are some practical constraints. Site requirements are established to determine suitable regions for osmotic power plants, and potentials are measured for selected regions.

KEYWORDS: Draw Solution, Feed Water, Osmotic Membrane Unit, Power Generation, Power Plant, Pressure Retarded Osmosis.

INTRODUCTION

Sydney Loeb first suggested Pressure retarded osmosis (PRO) and it describes the energy of combining a concentrated brine solution with a diluted solution. In action, PRO can extract osmotic energy when concentrated and diluted solutions are separated by a selective semi-permeable membrane, which allows water to pass but rejects most of the ionic species. The concentrated solution (draw solution) is pressurized and pumped into the PRO membrane which separates the diluted solution (feed solution) from the draw solution. The difference in osmotic pressure between the draw and feed solution induces fresh water movement across the membrane which dilutes the draw solution [1]. The pressurized draw solution goes to a special hydro-turbine power generation system. The PRO method is a feasible technology but most of the testing has been on a laboratory scale and there have been few pilot plants. The advances in membrane technology have solved the question of finding a suitable PRO membrane which was once an impediment to field-scale technology demonstration and testing.

Toyobo is one of the pioneering companies that successfully developed and tested PRO membranes for demonstration at a large-scale pilot plant. Hollow fibre FO membranes provided by Toyobo come with a wide active area of up to 700 m² and a feed pressure of up to 30 bars which makes them suitable for handling a salinity gradient with an osmotic pressure difference of 60 bars. PRO membranes will have a fairly high rate of rejection of ionic species to minimize reverse salt diffusion, and transfer of ions from drawing and feeding solutions. Carbon consumption is a major part of our everyday lives. The rate of energy consumption is increasing quite rapidly daily. If that continues as such then one day the planet will face energy shortages. While it's time to look for more energy sources rather than non-renewable energy sources and reduce the rate of non-renewable energy use. There are many types worldwide of renewable energy sources. The plentiful renewable energies include solar, tidal, wind, Geo thermal energy etc. One of the most recent techniques for generating power is osmotic control [2].

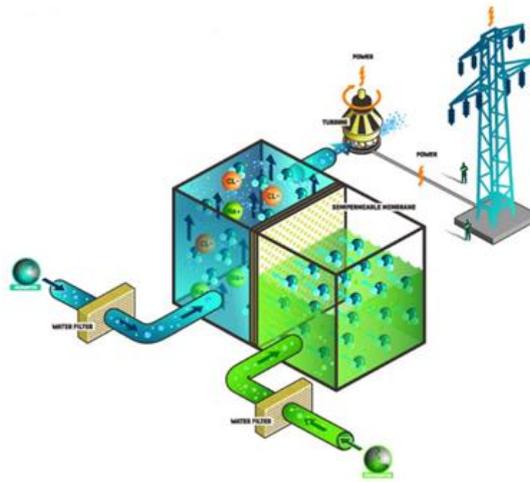


Figure 1: Osmotic Power Concept

The energy available from the difference in salt concentration between seawater and the river water is the osmotic power or salinity gradient power. Salinity gradient power is a particular option for renewable energy that produces renewable and sustainable power through the use of natural processes [3].

OSMOTIC POWER GENERATION PRINCIPLE

Osmosis is the basic concept involved in generating osmotic force. Osmosis is the movement of solvent molecules into a region of higher solute concentration through a selectively permeable membrane, with the goal of equalizing the concentrations of the solutions on both sides. This may also be used to describe a physical process in which any solvent passes through a semi-permeable membrane, without energy input (permeable to the solvent but not the solute), separating two solutions with different concentrations.

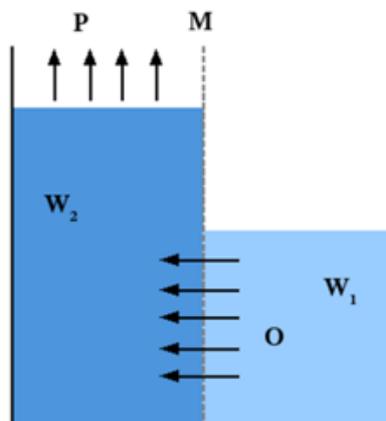


Figure 2: Principle of Osmotic

Salinity gradient energy is focused on using osmotic pressure differential between fresh water and sea water tools. All energy proposed to use salinity gradient technology is focused on evaporation in order to isolate water from salt. Osmotic pressure is the concentrated and diluted salt chemical potential. Looking at relationships between high and low osmotic pressure, solutions with higher salt concentrations show higher strain [4].

DEFINITION OF POTENTIAL TERMS

A renewable energy source's theoretical potential is the actual cumulative available energy in a specific area over a given period of time. The theoretical potential of mixing for salinity power plants is given by the Gibbs free energy. This is determined by assuming that the ocean and river water are absolutely, preferably mixed [5]. The temperature and salinity of river and ocean water, as well as the river water discharge into the ocean are criteria for measuring the theoretical potential. Since the river water flow into the ocean is very low relative to the world ocean water volume, the mixing ratio of ocean and river water is believed to be infinite. A limited proportion of the theoretical potential is exploitable. While the technological ability takes into account the technological constraints of the method of energy conversion in osmotic power plants with the use of a scientific power plant model. The scientific potential is a branch of potential theory [6].

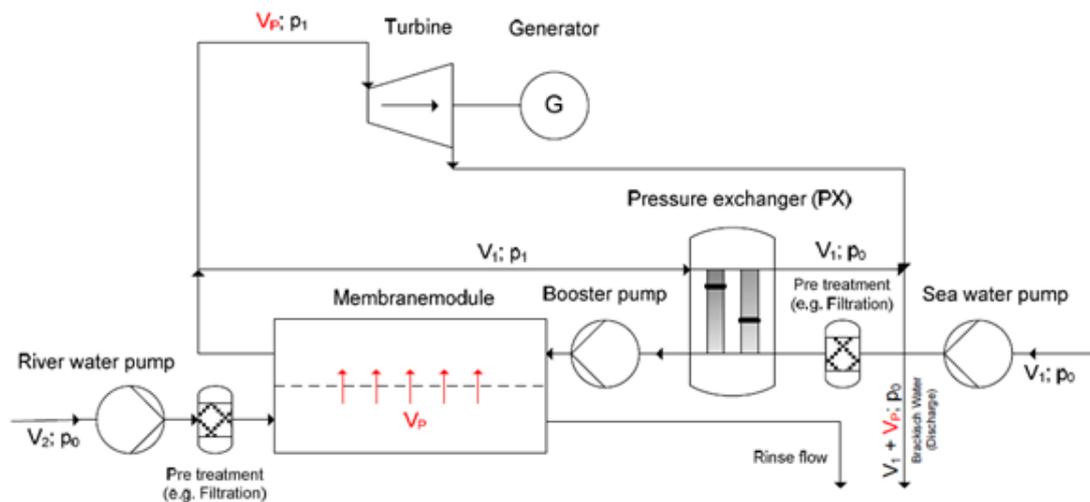


Figure 3: Power Plant Configuration

The process configuration for the osmotic power plant under review is shown in Fig. 3. The future assessment is based upon the principle of Pressure-Retarded-Osmosis (PRO). The technical basis data for calculating the net performance of the electrical power plant and the technical basis data for the components of the power plant, the operating point is defined by the pressure ratio p/π ratio between the pressure difference in the membrane modules α and the mean osmotic pressure in the membrane modules and the permeation factor ratio between permeate and river water. The electric energy generated is determined using the capacity factor and the net performance of the power plant [7].

ADVANCES IN THE PRO PROCESS

Osmotically controlled processes suffer from self-deficiencies due, respectively, to the effects of diluted and condensed concentration polarization at the drawing and feed solutions. When fresh water permeates through the membrane, the drawing solution becomes more diluted while the feed solution becomes more concentrated and thereby decreases the driving force of osmotic pressure through the membrane [8]. The phenomenon of polarization of concentration in the PRO and FO systems is unavoidable and has a negative impact on process performance. Dual stage PRO (DSPRO) is a process with a view to reducing the impact of concentration polarization and enhancing osmotic power plant efficiency. In action, feed concentration tends to decrease the osmotic pressure gradient and water flux in osmotically controlled membrane processes. Pressure-driven membrane processes in which concentration polarization occurs on the feed side experience concentration polarization on both sides of the membrane. The concentrated drawing solution from the first stage of the PRO method is replaced in the DSPRO method by a fresh drawing solution for fresh water exchange with the already pressurized drawing solution from the first stage [9].

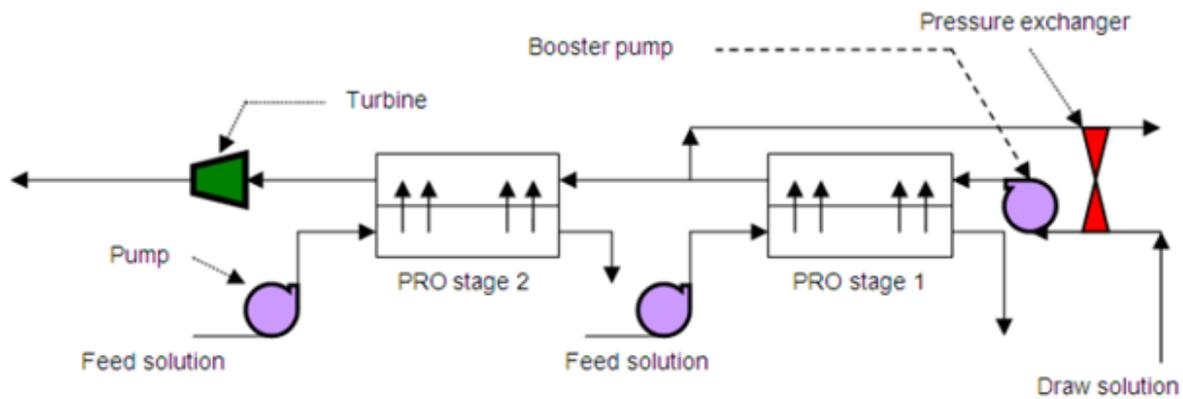


Figure 4: Dual Stage Pressure Retarded Osmosis Plant.

The second stage of the DSPRO process needs a small membrane region, because the draw solution's flow rate in the first stage of the DSPRO process will be equal to the permeate flow. The first stage of the DSPRO process to exchange pressure with the draw solution as shown in figure 4, a portion of the pressurized draw solution equal to the initial flow rate of the draw solution is recycled to a pressure exchanger. The pilot plant demonstration at Stat Kraft, the expense of PRO membrane has been reduced. The cost of PRO membrane Toyobo hollow fibre, HP10 Series, is close to that of RO membrane. The membrane has an active area of 700 m² and has a feed pressure of 30 bars which makes it a good match for several resource gradients with salinity [10].

OPEN AND CLOSED CYCLE HYDRO-OSMOTIC POWER PROCESS

There are a variety of ways to recover condensed and salty solutions osmotic or chemical strength. In seawater and freshwater an open cycle system up to 50 per cent of the OE can be recovered through a semi-permeable membrane. The low salinity water, Feed Water (FW), is fed to one side of an Osmotic Membrane Unit (OMU) at low osmotic and hydraulic pressures, while a Draw Solution (DS), e.g. seawater or brine, is fed to the other side at higher osmotic and hydraulic pressures, where the DS hydraulic pressure is usually less than the osmotic pressure. The concentrated discharged FW is circulated to the source of freshwater, while the diluted DS is used to run a turbine for power generation. A more efficient cycle can be accomplished by recycling some of the pressurized solution, leaving the OMU and assisting with the pumping of the brine to the OMU via a PES. This method is implemented when a continuous supply of freshwater and seawater, e.g. at a river run-off point to a sea or salt lake is given [11].

A closed cycle HOP farm, where DS can replace seawater, is also suggested. The drawing agent is maintained in the device using a Regeneration Unit (RU), which can be another technique of separation, such as evaporation, crystallization, or separation of membranes. The produced hydraulic pressure can be used in the closed cycle HOP plant to generate electricity similar to the open cycle method, or could be transferred to other liquids for pumping processes via a PES. The performance of the closed HOP device depends on the availability to regenerate the osmotic agents of a low-grade energy supply and/or renewable energies. Renewable sources of energy include solar, geothermal and wind for evaporation in hot and dry climates, or cold temperatures for crystallization in cold climates, and/or waste heat from power plants and chemical plants. Recent improvement to the closed-cycle method is achieved with the use of ammonia-carbon dioxide solution as DS, which is regenerated by thermal separation.

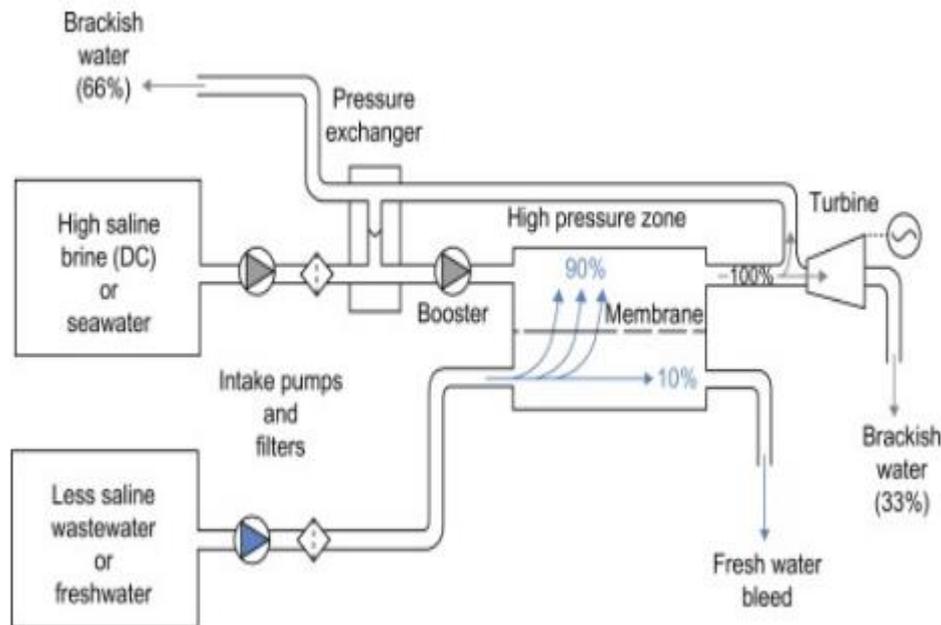


Figure 5: Osmotic Power through Pressure-Retarded Osmosis.

The idea of osmotic power generation was first suggested by Prattle; research interest in PRO has increased through efforts to exploit the saline gradient between two sources, especially at the point where freshwater coexists with saline water, such as seawater. The primary criterion of a draw solution for PRO from the point of view of power generation should be water induction capacity, i.e. high osmotic pressure, because power density is directly proportional to water flux. By applying the PRO technology to an area where low salinity water meets seawater, electricity generation is easily accomplished through a stand-alone PRO without further processing for recovery of the solution. PRO's development of renewable energy from seawater is attracting considerable attention because seawater is a massive, unexploited resource. The total power production capacity of PRO is projected at 2000 TWh per annum. In addition to natural seawater, highly concentrated RO brine also possesses tremendous potential as a PRO draw solution. Thus, several combinations of PRO and Seawater Reverse Osmosis (SWRO) systems have recently been proposed to improve the overall capacity, energy consumption, and brine management efficiency of the desalination cycle [12].

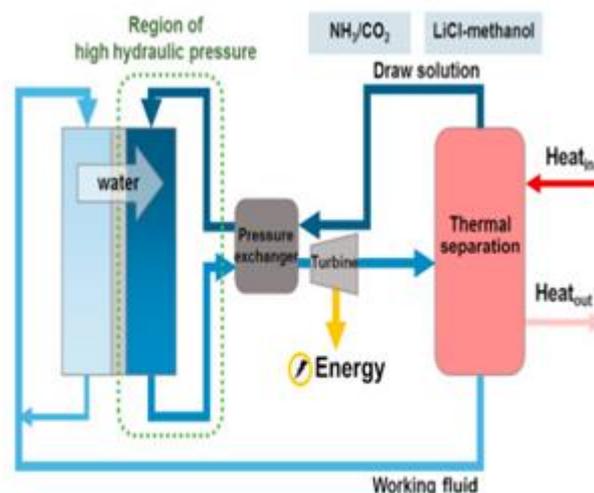


Figure 6: An Osmotic Heat Engine (OHE) System.

PRO's efficiency is still limited by the lack of suitable membranes and the drawing of solutes. A major advance in membrane production should therefore be achieved first, and thorough progress in device optimization and the selection of solute drawing are also required.

CONCLUSION

Osmotic power plant is a new renewable energy source which can be further built for generating electricity. Given the large number of laboratory scale experiments, there are very few attempts at pilot plant research. Power generation from a resource with a salinity gradient is strongly influenced by the concentration of feed and draw solutions and the PRO membrane characteristics. PRO membranes are available commercially and can be ordered from Toyobo or Toray to the RO membranes at a reasonable price. The impact of concentration polarization on the feed side, DSPRO process is able to increase the efficiency of the PRO cycle. Osmosis is the movement of solvent molecules into a region of higher solute concentration through a selectively permeable membrane, with the goal of equalizing the concentrations of the solutions on both sides. The phenomenon of polarization of concentration in the PRO and FO systems is unavoidable and has a negative impact on process performance. Dual stage PRO (DSPRO) is a process with a view to reducing the impact of concentration polarization and enhancing osmotic power plant efficiency. The PRO technology to an area where low salinity water meets seawater, electricity generation is easily accomplished through a stand-alone PRO without further processing for recovery of the solution.

REFERENCES

- [1] F. Helfer, C. Lemckert, and Y. G. Anissimov, "Osmotic power with Pressure Retarded Osmosis: Theory, performance and trends - A review," *Journal of Membrane Science*. 2014, doi: 10.1016/j.memsci.2013.10.053.
- [2] E. Sinibaldi, A. Argiolas, G. L. Puleo, and B. Mazzolai, "Another lesson from plants: The forward osmosis-based actuator," *PLoS One*, 2014, doi: 10.1371/journal.pone.0102461.
- [3] B. J. Feinberg, G. Z. Ramon, and E. M. V. Hoek, "Thermodynamic analysis of osmotic energy recovery at a reverse osmosis desalination plant," *Environ. Sci. Technol.*, 2013, doi: 10.1021/es304224b.
- [4] E. Sinibaldi *et al.*, "Osmotic actuation modelling for innovative biorobotic solutions inspired by the plant kingdom," *Bioinspiration and Biomimetics*, 2013, doi: 10.1088/1748-3182/8/2/025002.
- [5] B. R. Bruhn, T. B. H. Schroeder, S. Li, Y. N. Billeh, K. W. Wang, and M. Mayer, "Osmosis-based pressure generation: Dynamics and application," *PLoS One*, 2014, doi: 10.1371/journal.pone.0091350.
- [6] J. Cheng, Y. Zhu, Z. Zhang, and W. Yang, "Modification and improvement of microalgae strains for strengthening CO₂ fixation from coal-fired flue gas in power plants," *Bioresource Technology*. 2019, doi: 10.1016/j.biortech.2019.121850.
- [7] A. Naghiloo, M. Abbaspour, B. Mohammadi-Ivatloo, and K. Bakhtari, "GAMS based approach for optimal design and sizing of a pressure retarded osmosis power plant in Bahmanshir river of Iran," *Renewable and Sustainable Energy Reviews*. 2015, doi: 10.1016/j.rser.2015.08.018.
- [8] D. Hofius, L. Li, A. Hafren, and N. S. Coll, "Autophagy as an emerging arena for plant-pathogen interactions," *Current Opinion in Plant Biology*. 2017, doi: 10.1016/j.pbi.2017.04.017.
- [9] E. M. Kramer and D. R. Myers, "Osmosis is not driven by water dilution," *Trends in Plant Science*. 2013, doi: 10.1016/j.tplants.2012.12.001.
- [10] D. Cohen-Tanugi and J. C. Grossman, "Nanoporous graphene as a reverse osmosis membrane: Recent insights from theory and simulation," *Desalination*, 2015, doi: 10.1016/j.desal.2014.12.046.

- [11] D. D. Anastasio, J. T. Arena, E. A. Cole, and J. R. McCutcheon, "Impact of temperature on power density in closed-loop pressure retarded osmosis for grid storage," *J. Memb. Sci.*, 2015, doi: 10.1016/j.memsci.2014.12.046.
- [12] S. S. Merola, C. Tornatore, L. Marchitto, G. Valentino, and F. E. Corcione, "Experimental investigations of butanol-gasoline blends effects on the combustion process in a SI engine," *Int. J. Energy Environ. Eng.*, 2012, doi: 10.1186/2251-6832-3-6.

