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Review

Osmotic power with Pressure Retarded Osmosis: Theory, performance and trends – A review

Fernanda Helfer [a,*], Charles Lemckert [a], Yuri G. Anissimov [b]

[a] School of Engineering, Griffith University, Australia
[b] School of Biomolecular and Physical Sciences, Griffith University, Australia

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ABSTRACT

A great quantity of renewable energy can be potentially generated when waters of different salinities are mixed together. The harnessing of this energy for conversion into power can be accomplished by means of the Pressure Retarded Osmosis (PRO). This technique uses a semipermeable membrane to separate a less concentrated solution, or solvent, (for example, fresh water) from a more concentrated and pressurized solution (for example sea water), allowing the solvent to pass to the concentrated solution side. The additional volume increases the pressure on this side, which can be depressurized by a hydroturbine to produce power – thus the term 'osmotic power'. This paper reviews technical, economical, environmental and other aspects of osmotic power. The latest available research findings are compiled with the objective of demonstrating the rapid advancement in PRO in the last few years – particularly concerning membrane development – and encouraging continued research in this field. Also, the hurdles involved in the effectuation of PRO plants and the research gaps that need to be filled are analyzed in this article. Additionally, osmotic power production using configurations other than the traditional pairing of river water and sea water are discussed. It is hoped that this review will promote further research and development in this new and promising source of renewable energy.

Contents

* Correspondence to: Griffith School of Engineering, Gold Coast Campus, Room 1.09, G09, Southport, QLD 4222, Australia. Tel.: +61 07 55527886.
E-mail addresses: f.helfer@griffith.edu.au, fehelfer@gmail.com (F. Helfer), c.lemckert@griffith.edu.au (C. Lemckert), y.anissimov@griffith.edu.au (Y.G. Anissimov).

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1. Introduction

Global energy supply for human activities is dominated by fossil fuel combustion [1], which due to high emissions of greenhouse gases, is accelerating changes in our climate towards dangerous long-term effects [2,3]. It is estimated that only 13% of our energy is sourced by renewable resources, mainly shared between biomass and waste (75%), hydro (17%) and solar and wind (6%) [1]. Geothermal, wave and tidal energies account for the rest of the share (2%). To reduce the reliance on fossil fuels while also satisfying growing energy requirements, new alternative sources have to be explored and embraced, particularly renewable sources due to the smaller impact on our environment.

A type of renewable and gas emission-free energy that has just recently been given credibility is salinity-gradient energy, which is based on the release of free energy upon mixing of waters with different salt concentrations, as between rivers and oceans. When appropriately harnessed, this energy can be used to produce power [4].

In the context of this review, the process of harnessing salinity-gradient energy is best explained in terms of osmotic pressure. Osmosis occurs when two solutions of different concentrations (for example, different salinities) are separated by a membrane which will selectively allow some substances through it but not others. If these two solutions are fresh water and sea water, for example, and they are kept separated by a semipermeable membrane that is only permeable to water, then water from the less concentrated solution side (fresh water) will flow to the more concentrated solution side (sea water). This flow will continue until the concentrations on both sides of the membrane are equalized or the pressure on the concentrated solution side is high enough to stop further flow. Under no flow conditions, this pressure will be equal to the osmotic pressure of the solution. Osmotic pressure of a given solution is therefore not a pressure that the solution itself exerts, but a pressure that must be applied to the solution (but not the solvent) from outside in order to just prevent osmotic flow.

Pressure Retarded Osmosis (PRO) is the process through which osmotic energy can be harnessed and power generated [5]. Putting it simply, in PRO, a water flow is diverted at low pressure into a module wherein a semipermeable membrane keeps it separated from a pressurized and saltier water flow. The saltier water flow draws the less concentrated water through the semipermeable membrane due to its higher osmotic pressure, increasing the volume of the flow. A turbine is coupled to the pipe containing the increased pressure flow to generate power. Power generated via PRO is referred to as ‘osmotic power’.

The most known and studied application of PRO technology for power generation is the pairing of river water (less concentrated solution or feed solution) and sea water (more concentrated solution or draw solution), as schematized in Fig. 1. Under this arrangement, incoming river water and seawater are both diverted into adjacent chambers of a membrane module. The two flows are separated by a semipermeable membrane with the active layer facing the seawater side, allowing only river water to flow through it. This process increases the volume of water on the seawater side. The resultant high-pressure, brackish water is then split into two paths: part of the flow is used to drive a turbine, and generate power, and the other part returns to the pressure exchanger. The pressure exchanger is designed to transfer pressure energy from the pressurized brackish water to the incoming sea water. Similarly, sea water could also be used as feed solution, paired with a more concentrated solution, such as brine from seawater desalination plants [6–8], or hypersaline water from salt lakes or salt domes [9,10].

PRO was invented by Prof. Sidney Loeb in 1973 at the Ben-Gurion University of the Negev, Beersheba, Israel, with his first publication released in 1975 [5]. The method has been improving over the years, particularly after the opening of the first osmotic power plant prototype by the Norwegian state-owned power company, Statkraft, in 2009 [12]. This prototype has been designed to develop and test new PRO technologies, particularly novel semipermeable membranes, and is projected to become the first large-scale osmotic power production facility in the world by 2015 [13]. The plant operates using river water and sea water, as shown in Fig. 1.

This article analyses technical, economical, environmental and other aspects of PRO. It combines the findings of the latest research, outlining the advancements achieved in the last few

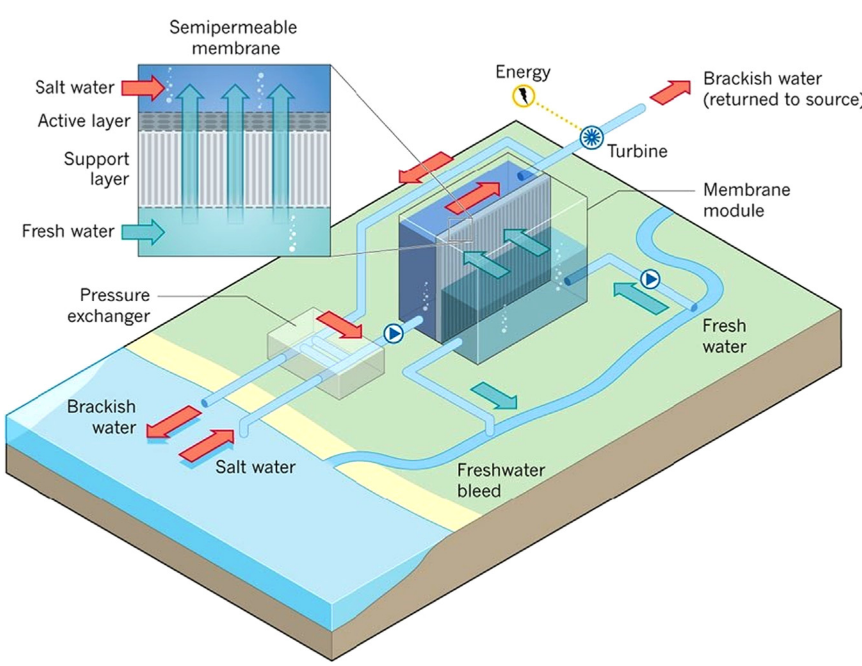

Fig. 1. Schematic diagram of a PRO plant run on river water *vs.* sea water.