Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 34 (2013) 211 – 217

Energy Procedia

10th Eco-Energy and Materials Science and Engineering
(EMSES2012)

Applicability of Pressure Retarded Osmosis Power Generation Technology in Sri Lanka

H.D.S.S. Karunarathne[a,]* and S. Walpalage[a]

[a]University of Moratuwa, Moratuwa(10400), Sri Lanka

Abstract

In this study the applicability of pressure retarded osmosis power generation was investigated in order to fulfil current electricity demand in Sir Lanka. Pressure retarded osmosis (PRO) process is a renewable and green technology with zero carbon emission to the environment. Salinity gradient through a membrane is the key parameter in osmotic pressure development. Theoretically it is a pressure increment of 26 bar which is equivalent to 270 m high water column for fixed volume of salt water compartment. This hydrostatic pressure can be used to generate electricity by sending pressurized water through a turbine. According to the literature, 1 MW electricity generation requires $1m^3/s$ flow of fresh water.

Sri Lanka has a great potential to develop this technology as it is surrounded by sea. Subsequently the country is having 103 number of water rich river basins over the country. Currently the electricity demand of the entire country is about 2100MW and it is already being supplied by both hydro and thermal power plant. The country spends an immense amount of money for the thermal power generation in every year. This can be reduced by introducing PRO power generation. Calculations over the PRO power generation reveal that it is possible to generate 7.84% of country energy requirement via some selected river basins through this technology.

Keywords: Osmotic Power; Pressure retarded Osmosis;

* Corresponding author. Tel.: +94-714-824-598; fax: +94-112-650-281.
E-mail address: sumuduunimrt@gmail.com.

doi:10.1016/j.egypro.2013.06.749

1. Introduction

Owing to the high energy consumption of the world, the rate of depletion of natural fossil deposits accelerates every day. Thus it is essential to put the maximum drive to find new energy sources and develop existing technologies to achieve high efficiency. By virtue of that the world is looking for cost-effective renewable energy sources to establish the sustainability among the world’s energy requirement [1].

In a country, the availability of energy plays a major role in development process. Inadequate supply of power is considered as the main issue for economic and social development [2].According to the statistics, Sri Lanka has an electricity demand about 2100 MW considering both parties of domestic and industrial sectors [3]. The main electricity generation is done with the contribution of both hydro and thermal power stations in which 40 % is generated by hydro stations including mini hydro plants. The rest of 60 % is generated by thermal power stations. Table1 shows the current electricity generation statistics in year 2011 according to the statistics of Ceylon Electricity Board. There the average unit generation cost by hydro power and thermal power generations are about Rs. 1.71 and Rs. 14.33 respectively.

In addition to hydro and thermal power generation, country is planning to expand the renewable energy sector by developing dendro, wind and solar power generations. In general 1MW of dendro power plant requires about 400 hectares of land to provide necessary fuel requirement. Further, plantation of crops takes a long time and uncertainty of sustainable supply creates negative impact on dendro power generation.

Table 1. Gross Electricity generation in Sri Lanka in 2011

Source	GWh
Hydro	4622
Thermal-Oil & Coal	6785
NCRE	121

Several international agencies have done feasibility studies to identify the wind resource potential areas in order to install wind mills with the collaboration of the local authorities. It has been found that there are nearly 5000 Km^2 of wind areas with good-to-excellent wind resource potential in country. Though such places have been identified and studied maximum utilization was not been achieved owing to issues faced in wind power development [4].

Pressure retarded osmosis (PRO) power generation is an upcoming green technology to generate electricity at zero green house gas emission [5].Salinity gradient power is known as sustainable and totally renewable and has the highest energy concentration (energy density) among the marine renewable energy sources [6].Since 1997 the North European power producer Statkraft has engaged in the research and development of osmotic power and currently they are the world leader in this development[7].The world’s first prototype PRO plant started operations in 2009 in the southeast of Norway. The main objectives of the prototype were to confirm that the design system could produce power on a reliable 24-hour/day production and for the testing of technology for further improvement of efficiency [5].

Sri Lanka is an island surrounded by Indian Ocean having a land area of 65510 km^2. Country has 103 distinct river basins, and most of the main rivers originate in the hill country and eventually flow into the sea, passing through the lowlands [8]. Thus it is a great advantage to have such water rich river basins in order to implement PRO technology in Sri Lanka to uplift the country electricity facility in sustainable way.

In this study the applicability of PRO process is investigated in terms of the power which can be generated through several selected water basins. Further total power was calculated and compared while changing the water flow used for the PRO process.

2. Theory

2.1. Osmosis Process

Transportation of water from a dilute to more concentrated solution through a membrane is known as the osmosis [9]. When the water flow into a concentrated area the solute concentration decreases. The tendancy for water to flow throgh the membrane is expressed as osmotic pressure $\Delta\pi$ [10]. A schematic presentation of presure retatded osmosis is shown in Fig.1.Osmotic pressure can be quantify according to the Van't Hoffs law.

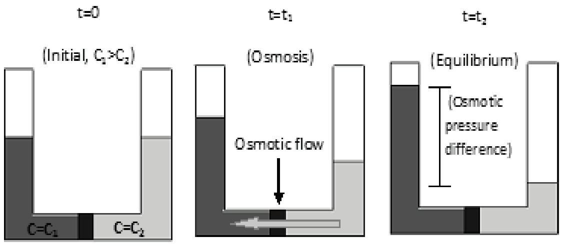

Fig.1. Schematic presentation of pressure retarded osmosis

$$\Delta\pi = \frac{Z.C.R.T}{M_w} \tag{1}$$

where Z: Valance, C: Concentration (kg/m^3), R: Universal gas constant (J/K.mol), T: Temperature (K), M_w: Molecular weight (kg/mol).

The concentration profile of salt through the membrane is shown in Fig.2. The phenomenan of concentration polarization make a severe effect on membrane performance that it reduces effective osmotic pressure difference across the membrane [9,11].

2.2. Salinity power

The pressure build during the osmosis can be used for the power generation. It is called as the salinity power and the principle is known as pressure retarded osmosis. Literature revials that for a fixed volume of saltwater compartment the theoritical approximation of pressure increment will be 26 bars.This is equavalent with 270 meter high water column [7].

The water flow at a pressure $\Delta P < \Delta\pi$ can be described by as follows for complete rejection.

$$J_v = A(\Delta\pi - \Delta P) \tag{2}$$

where J_V is the water flux and A is the permeability coefficient of the membrane.

The power E (Watt or J/s) per unit membrane area is given by the product of flux and pressure difference. i.e.

$$E = J_v.\Delta P \tag{3}$$

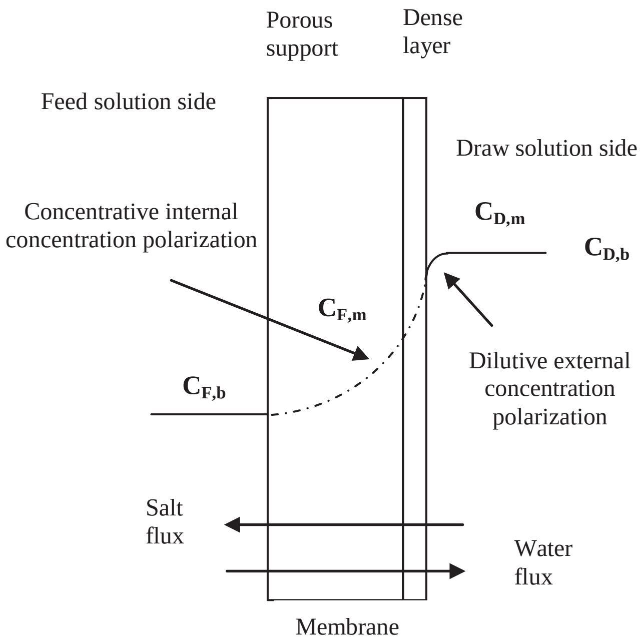

Fig.2. Concentration profile of salt through the membrane with concentration polarization

$$E = A(\Delta\pi - \Delta P).\Delta P \tag{4}$$

Differentiating Eq. 4 with over ΔP gives the rate of change of energy with respect to ΔP .Thus at maximum power

$$\frac{dE}{d\Delta P} = 0 \tag{5}$$

$$E = E_{max} \tag{6}$$

The maximum power (W/m^2) can be obtained when the pressure is at a value of half of the Osmotic pressure.

$$\Delta P = 0.5\pi \tag{7}$$

Thus maximum power can be generated is [9]

$$E_{max} = 0.25.A.\pi^2 \tag{8}$$

Higher the gradient between salinity in the fresh and saltwater, more pressure will build up in the system [5]. Practically the optimal operating pressure would be in the range of 10 to 15 bars equivalent to a water head of 100 to 145 meters in a hydropower plant [12]. Theory reveals that a stream flowing at 1m^3/s will be able to produce 1MW electric power [6].Power generation can be increased by increasing the fresh water flow rate. In addition to that power density of the membrane is an important factor in PRO in which it should be in a range of 4-6 W/m^2.

2.3. PRO Process

In this process, the river water (low salt) and see water (high salt) are fed in to the plant. It is required to filter the both water streams before enter the membrane modules in order to prevent fouling the membranes due to particulate matters. This pre treatment depends according to the water quality. Fig.3. Present the schematic of pressure retarded osmosis power plant.

Membrane modules can be either hollow fiber or spiral wound membranes and 80-90% of the water with low salt gradient is transferred by osmosis across the membrane into the pressurized salty water [12]. Pressurized salt water is sent in to the turbines to generate electricity. In order to PRO to be economically viable, power density with 5 W/m^2 is necessary to generate electricity cost effectively [13].The objective of having pressure exchanger is used to recycle a part of energy which is carried by brackish water in order to enhance the pressure of feed salty water.

There are several essential facts that have to be considered before installing a PRO power plant in a particular river basin. The amount of water in the river, qualities of fresh and sea water, characteristics of the membranes and physical and chemical conditions in the estuary must be considered in order to develop an economically viable PRO power plant.

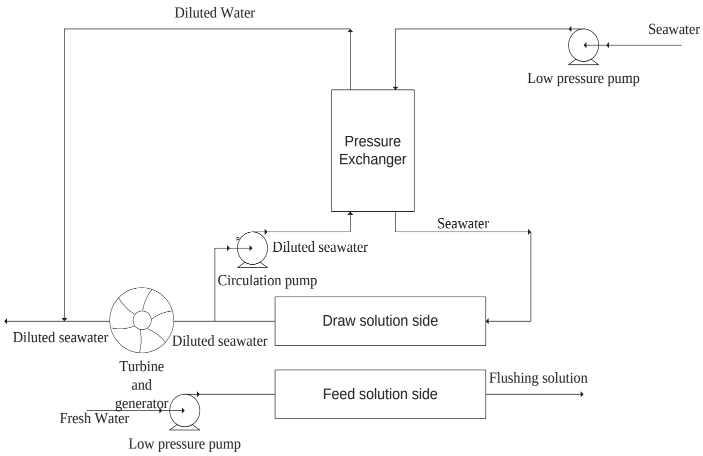

Fig. 3. Schematic of a pressure-retarded osmosis (PRO) power plant

3. Methodology

Initially several river basins was selected considering the water flow around and above 450 MCM (millions cubic meters per year). The annual water discharge volume to sea from each river is given as MCM in Table 2. Accordingly the electricity power which could be generated via PRO process was calculated for selected rivers under particular 5% of inlet water flow rates of river basin. Then the percentage of power from PRO process over national demand was calculated. Further the amount of power could be generated was calculated for several percentages (10, 15, 20 %) of water flow of river basin.

4. Results

Individual electricity generation over selected river basins was calculated according to the equation 9. The power which could be extracted by PRO process under the 5% flow rate of river flow is shown in the Table 2.

$$Power\ (P) = Power\ \ per\ Unit\ Volume\ (W / m^3) \times Flow\ rate\ (m^3) \tag{9}$$

According to the electricity power calculation, results reveal that 62.77 MW could be generated from selected river basins.

Table 2. Power extracted by PRO process using 5% of river total water flow rate.

River	Flow rates		Power (MW)
	MCM	m^3/s	
Attanagalu Oya	845	26.79	1.34
Benthara Ganga	1247	39.54	1.98
Bolgoda Ganga	485	15.38	0.77
Daduru Oya	1129	35.80	1.79
Gal Oya	1679	53.24	2.66
Gin Ganga	2179	69.10	3.45
Kala Oya	855	27.11	1.36
Kalani Ganga	5579	176.91	8.85
Kalu Ganga	8143	258.21	12.91
Kirindi Oya	428	13.57	0.68
Kumbukkan Oya	428	13.57	0.68
Ma Oya	300	9.51	0.48
Maduruu Oya	777	24.64	1.23
Maha Oya	1485	47.09	2.35
Mahavali	8140	258.12	12.91
Malwathu Oya	566	17.95	0.90
Manik Ganga	484	15.35	0.77
Mundenu Aru	781	24.77	1.24
Nilwala Ganga	1379	43.73	2.19
Walawe Ganga	2200	69.76	3.49
Yan Oya	482	15.28	0.76

Power can be increased by increasing the allocated river water flow rate to the PRO process. Table 3 shows how the power generation increases with the increase of use of river water flow percentage for the PRO process.

Table 3. Increases of power generation with the increase of percentage of river flow for the PRO process

Percentage of water used for PRO process	Power generated by PRO process (MW)
5%	62.77
10%	125.54
15%	188.31
20%	251.08

Finally under different river water flows, the percentage of power generation via PRO Process over country gross electricity generation was calculated and tabulated in Table 4.

$$Percentage \quad of\,energy\,generation = \frac{Energy \ via \ PRO}{Total \ \ Energy \ Generation} \qquad (10)$$

Table 4. Percentage of PRO power generation under different river flows.

Source	Expexted Power generation (%)			
	5%	10%	15%	20%
PRO	1.96	3.92	5.88	7.84

5. Conclusion

In this investigation it is identified that Sri Lanka is rich with resources for the development of PRO power generation and can achieve a level where the conventional thermal power generation can be minimized. According to the calculation for the selected river basins approximately 7.84% of gross electricity generation can be generated by PRO process under the 20% of total river flow. This can be increased further by increasing the number of selected river basins and flow rates.

After consideration and analysis of the results it is suggested that PRO process is a suitable green technology which can be implemented successfully in Sri Lanka. In addition to that PRO process enables to qualify for green certificates and other supportive policy measures for renewable energy.

Acknowledgment

Authors wish to thank University of Moratuwa research grant scheme for providing funds for the research project. We appreciate the support given by the staff of the University Library and Department of Chemical and Process Engineering, University of Moratuwa

References

[1] Sharif, A.O., Merdaw, A.A., Sanduk, M.I., Al-Aibi, S.M. and Rahal, Z. 2011. The potential of chemical-osmotic energy for renewable power generation. In *World renewable energy congress*. Linkoping, Sweden, 8-13 May.

[2] Ferreira, R. and Estefen, S. 2011. The potential of chemical-osmotic energy for renewable power generation. In *World renewable energy congress*. Linkoping, Sweden, 8-13 May.

[3] Annual report, Ceylon Electricity Board, 2011

[4] Ariyadasa, L., Current status of the energy situation in sri lanka.

[5] Skramesto, O.S., Skilhagen, S.E. and Nielsen, W.K. 2009. Power production based on osmotic pressure. Article; Waterpower XVI.

[6] Jones, A.T. and Finley, W. 2003. In *proceeding of Marine technology society OCEANS*.

[7] Skilhagen, S.E. and Aaberg, R.J. 2006. Osmotic power – power production based on the osmotic pressure difference between fresh water and sea water. *Owemes*. Citavecchia, Italy, 20-22 April.

[8] Manchanayake, P. and Bandara, C.M.M., 1999. Water resources of sri lanka, National Science Foundation.

[9] Achilli, A.; Cath, T.Y.; and Childress, A.E.. 2009. Power generation with pressure retarded osmosis: An experimental and theoretical investigation. Journal of membrane science 343:42-52.

[10] Rao, M. 2007. Reverse Osmosis. vol.12, No.5, pp.37-40.

[11] Liu, L., Wang, M., Wang, D. and Geo, C. 2008. Recent patent on chemical engineering, 2:76-82.

[12] Skilhagen, S.E., Dugstad, J.E. and Aaberg, R.J. 2007. Osmotic power-power production based on the osmotic pressure difference between waters with varying salt gradients. Desalination, 220:476-482.

[13] Yip, N.Y.; Tiraferri, A.; Phillip, W.A.; Schiffman, J.D.; Hoover, L.A.; Kim, Y.C., and Elimelech, E., 2011. Thin-film composite pressure retarded osmosis membranes for sustainable power generation from salinity gradients. Environ.sci.Technol.45:4360-4369.