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Modeling and design of a 25 MW osmotic power plant (PRO) on Bahmanshir River of Iran

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ABSTRACT

Osmotic energy is one of the renewable energies. This osmotic energy source is easily obtainable all over the world where river water flows into the ocean or sea. In this article, Bahmanshir River in Iran which falls into the Persian Gulf was considered as selected place for modeling and design of 25 MW osmotic power plant in PRO method. Results indicates that for a 15 year return on investment, annual increase in purchase price of electricity 10% and interest rate 6%, sale price of electricity should be 0.4117 €/KWh which is highly expensive compared to state's suggested price of electricity from renewable source (i.e. 0.09 €/KWh).

In order to balance purchase and sale price of electricity, unit price of intake and outfall, unit price of micro-filtration and interest rate should be reduced 9.1%, 15% and 25% respectively and $\Delta\lambda$ should be increase 4.3%.

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1. Introduction

Generation of clean and sustainable energies is vital regarding the disadvantages of fossil fuels including dioxide carbon emission and climate change problem. Using the density gradient between salt and freshwaters for energy generation is one of the new ideas proposed in the field of renewable energies. Osmotic power or salinity gradient power is a new form of renewable energy can be obtained from salinity difference between fresh water (river) and salt water (sea) [1–8]. The osmotic power generation has no CO_2 emissions [9]. Global potential of electricity production using this method has been estimated to be 1600 TWh per year [10]. This value is considerable considering that the global potential of electricity production from renewable energies is 10,000 TWh per year [11].

The phenomenon of osmosis was first explored by French physicist, Jean-Antione Nollet. 200 years after exploration, this phenomenon is still being developed experimentally [12]. Pattle in 1954 introduced the phenomenon of osmosis as an energy source. He recognized that, if river water be blended with sea water, large amount of energy will be released [13]. This energy can be extracted by membrane. The membrane technology was developed in 1960 and was used mainly in laboratories and specialized industrial applications [14]. Finally Sidney Loeb changed membrane application from laboratory use to commercial application through inventing cellulose acetate membrane [2]. Commercial use was developed by improving of new membrane technologies in 1970s [15–21]. The technology of membranes is still in development. Recently, fundamental studies have been done on PRO membranes power density [22–24]. The studies show that under lab-scale PRO power generation, the power density can be high as 12 w/m^2 [22] and 14 w/m^2 [23]. The developed PRO membranes have great potential for osmotic power harvesting. Reverse electro dialysis (RED) and pressure retarded osmosis (PRO) are the most common methods of obtaining energy from waters with different salinities [25–27]. Studies and potential assessments were conducted in Norway with PRO method and in Netherland with RED method. Norwegian Statkraft company carried out various studies on power plants in PRO method since 1997 and finally in November 2009 this company was launched the 4 KW PRO plant in pilot form. Statkraft aims to develop a full-scale osmotic power plant for commercial operation by 2015 [28].

Regardless of hydroelectric power plants, the installed capacity of renewable energies in Iran is just 219 MW which is

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inconsiderable compared to total electricity production capacity of country (i.e. 69,000 MW) [29]. Hence, Iran requires more investment on renewable energies such as PRO in order to achieve sustainable development. Having access to seawater such as Persian Gulf, Caspian Sea and Uremia Lake as high density salt water sources and river water, Iran has great potential to implement such energy source.

The PRO power plant performance was recently evaluated via prototype scale. Therefore in this paper we want scale up the prototype PRO power plant with today's technology. For this purpose Bahmanshir River in Persian Gulf catchment basin was selected as a place to establish osmotic power plant. The economic and technical modeling of a 25 MW PRO plant is derived and sale price of PRO electricity is discussed. A comprehensive sensitivity analysis is carried out considering the technology development scenarios. This study can provide insightful perspectives on the cost bottlenecks and cost reduction strategies of osmotic power plant in the PRO method.

The remainder of this paper is organized as follows: Osmotic Power plant site is described in Section 2. In Section 3 modeling of pressure retarded osmosis (PRO) power plant is provided. The result of modeling and design of 25 MW PRO power plant is provided in Section 4. The Sensitivity analysis for different scenarios and future developments are presented in Section 5 and 6 respectively. Concluding remarks is presented in Section 7.

2. Selected osmotic power plant site

Bahmanshir estuary, located in the south-west of Iran, is one of the main inland waterways in Iran. The length of Bahmanshir River is 78 km initiated from junction place of Karoon with Haffar and Bahmanshir and developed to Persian Gulf mouth. Compared to RED, PRO has more potential to blend high salinity water ($S_{Nacl,c} > 35g/l$) with river water [25]. Since Persian Gulf is considered as saline water, therefore in this paper, PRO method was adopted to study osmotic power plant on Bahmanshir River. Fig. 1 shows a scheme of design of osmotic power plant in the selected area.

3. PRO power plant modeling

3.1. General governing equations

In PRO method, two solutions with different salinities are exposed to each other with employment of semi-permeable membrane in which only water passes from membrane and solved salts are remained in it. Diluted solution penetrates inside concentrated solution through membrane. This is due to difference in molar free energy between two solutions which are called osmosis transmission [28]. Fig. 2 shows a schematic of PRO process.

In the balanced position, molar energy of both sides of membrane is equal and equation (1) which is known as Vant Hoff equation indicates this state [25].

$$\Delta\pi_{osm} = \frac{i.R.T}{M_i}\left(S_{i,c} - S_{i,d}\right) \tag{1}$$

where $\Delta\pi_{osm}$ is the osmotic pressure difference, index i is the ion concentration per dissociated solute molecule, index c is the indicator of saltwater and index d is the indicator of freshwater. R is universal gas constant. T represents the temperature in Kelvin, Mi is molar mass of considered salt and S indicates the salinity in g/1 [25]. Compressed amount of concentrated solution part can be converted to electricity discharging into turbine. This can be achieved through continuous process of diluted and concentrated solution and discharge into power plant. In this method we will never reach a balance and electricity production will be continues. If salinity of fresh waters and saltwater is in TDS (total dissolved solids) form, equation (2) is used to obtain osmotic pressure difference of saltwater and freshwater.

$$\Delta\pi_{osm} = \frac{2.R}{M_{Nacl}}\left(T_c.S_{Nacl,c} - T_d.S_{Nacl,d}\right) \times 10^{-2} \tag{2}$$

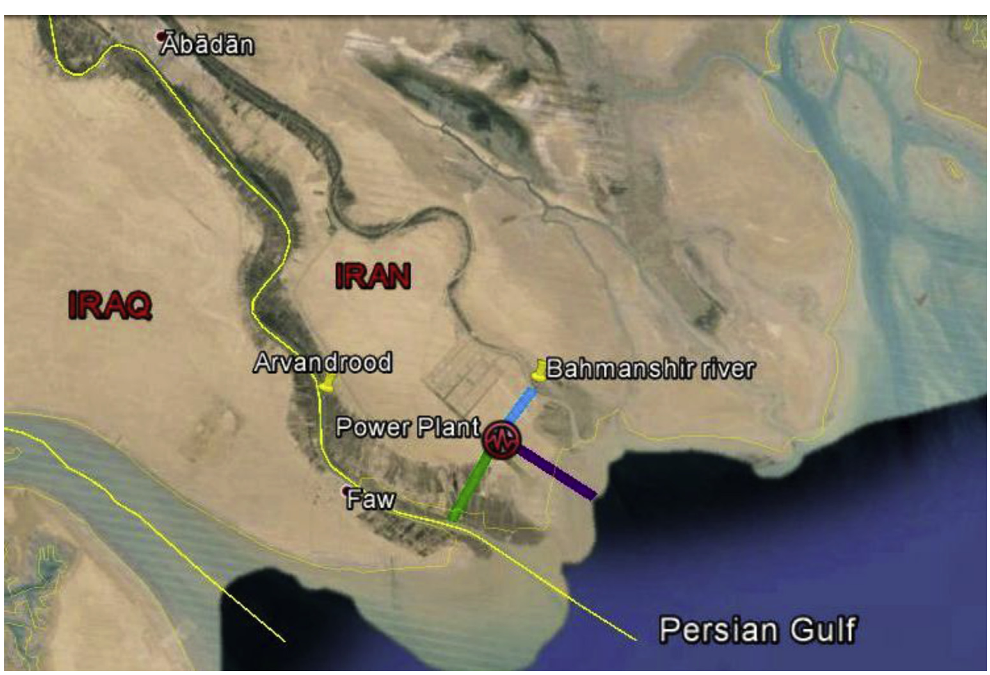

Fig. 1. Scheme of osmotic power plant in Bahmanshir. Dark blue arrow indicates salt water, pale blue arrow indicates freshwater and green arrow is the indicator of output water. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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