Power Generation from Salinity Gradient Using Reverse Electro-Dialysis in Lab Scale

Gholikandi Badalians Gagik [1*], Amirreza Arashi[2]

1. Associate. Professor, Environmental Engineering, Shahid Beheshti University, Tehran, Iran
2. MSc., Graduate, Water and Wastewater Engineering, Shahid Beheshti University, Tehran, Iran (kiarash.arashi@gmail.com)

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Expanded Abstract

Introduction

Nowadays, energy, water and environmental issues are the intersection of all human's requisites. Supplying energy from a wide range of clean sources is a reliable response in order to obtain all of the requisites of mankind. Salinity gradient power is a clean energy source that is available everywhere and has the capacity of supplying a reasonable amount of energy suitable to be used in various applications. This source of energy has gained a global approval and many researchers are trying to expand and optimize its industrialization.

Many various methods has been studied and presented for power generation from salinity gradient and they are almost the reverse of dominant desalination systems such as Reverse-Osmosis (RO) and Electro-Dialysis (ED). In the Reverse Electro-Dialysis (RED) method, a concentrated and a diluted salt solution are brought into contact through an alternative series of anion exchange membranes (AEM) as well as cation exchange membranes (CEM). By diffusion of anions and cations through the AEM and CEM from concentrate to dilute, are created in electrolyte which is converted into electric current in the wire by redox reaction on the active anode and cathode surface.

Operational parameters in the RED system are salinity difference, temperature and flow-rate, which shown by TDS, C and Q. I. In this research, the Taguchi method was employed to achieve the best operational condition.

Material and Methods

The experiments were designed by Taguchi methods and used by an Orthogonal Array (OA) M16 for determination of the operational conditions.

Variance and S/N analysis were used to determine the effects of each parameter on the objective function (watt per square meter of membrane used).

The experiment was carried out by a lab scale set up that is consisted of 10 RED cells with 11 AEM and 10 CEM (type II Fujifilm manufacturing Europe B.V) with 100 cm^2 effective area. The current head was supplied by earth gravity with 2 tanks in 1 meter upper than RED stack.

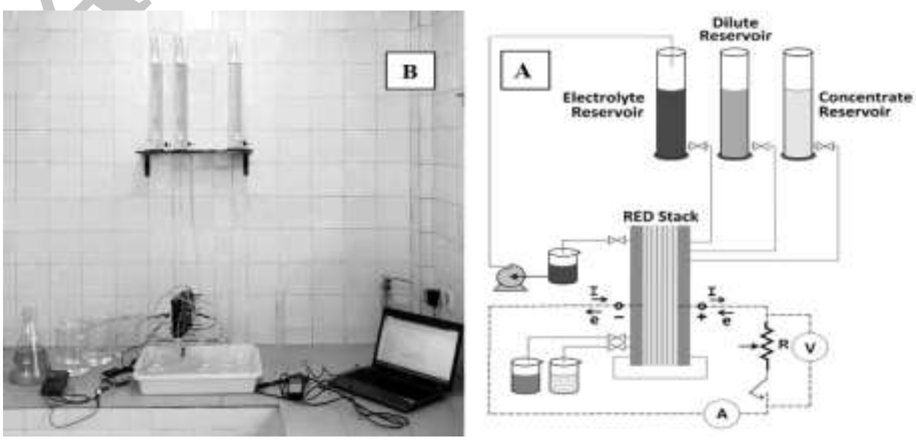

Fig. 1. Schematic diagram of RED system

∗ Corresponding Author: Tel: +98 9121430209 E-mail: g.badalians@yahoo.com

The pilot used in this study has been shown in Figure 1 schematically. 3 layer path flow tortuous spacers have been used and the thickness of the spacers were about 300 µm used for reduction of hydroelectric shortcut current effects.

The various solutions by different concentrations have been prepared in the laboratory. The stack has been formed from 10 cells. Each cell has obtained two compartments (dilute and concentrate) as well as the anionic and cationic membranes.

The electrodes were stainless steel with the thickness of 500 µm. The electrolyte solution is consisted of a 0.05 molar of $FeCl_3$ and $FeCl_2$ and 60 gr/L of NaCl, as the pH value was 2.

The voltage of the circuit was determined by Open Circuit Potential (OCP) method. The amounts of current and voltage values obtained in different temperatures and flow rates and salinity gradients (TDS) as operational conditions, have been used to calculate the output power which has been inserted into Taguchi method to be evaluated.

Results and Discussion

After determining the variables related to the structure, such as the distance between membranes during the early experiments to check the effects of factors and determine the optimum conditions of operating system in the Reverse Electro-Dialysis to generate electricity power, the experiments were consecutively done in 16 stages and each stage was repeated 3 times. Various factors considered in each stage were modified at different levels and the system operations to reach the sustainable condition. The amount of the rate of the current density and electrical potential difference was constant in 4 to 5 minutes after beginning the test.

Figure 2 illustrates the effect of temperature, flow rate and salinity gradient. In this graph, the horizontal axis indicates four levels considered for different amounts of each parameter and the vertical axis indicates S/N rate calculated from the experiments. According to Fig. 2 increase of the salinity gradient can increase the rate of power generation. Level 4 by 210 gr/lit salinity gradients had the highest power output.

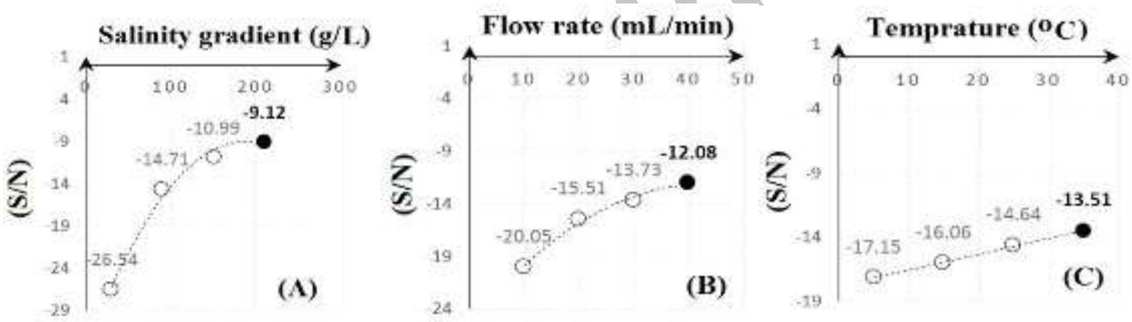

Fig. 2. The effect of temperature, flow rate and salinity gradient

After inserting the results of the tests into the QUALITECH-4 application, the ANOVA analysis of the tests results was carried out. The degree of freedom for each factor is the number of its surfaces minus one unit and the factor is the one of the quantities of which is available for different Orthogonal Arrays in the standard tables related to the method of Taguchi experiment. It can determine the rate of being effective or not for the considered factor in response to the system. According to the calculated amounts of the factor and its standard amounts in statistic references, all the selected factors are certainly 95 percent effective on generation efficiency of the electric power (The objective function in this research).

As specified from the above, concentration by 80.81 percent is the most effective factor in generating electric power in the Reverse $_{\text{Electro}}$-Dialysis (RED) method and temperature has the least effect by 3.29 percent on generating power in this process.

The results of experiments indicates that the maximum power output per square meter of the used membrane is resulted with 210 gr/L of concentration, flow rate equal to 40 mL/min and temperature equal to 25 degree centigrade.

Gholikandi Badalians Gagik, Amirreza Arashi

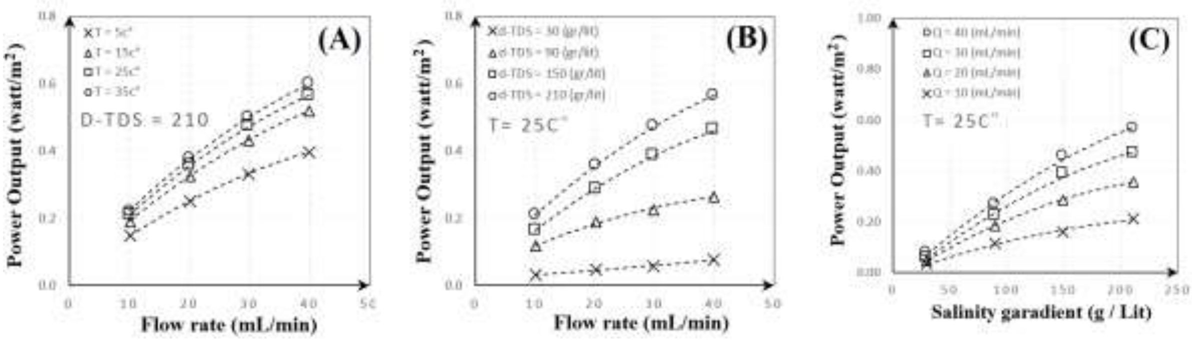

Fig. 3. Relation between flow rate, salinity gradient and power output

On the basis of the results obtained from/through the Taguchi method, the experiments were done under the optimum condition to determine the quality of parameter changes toward each other. Due to the least effect of temperature on the power of generating energy compared with other parameters, the optimum temperature was considered equal to 25 degree centigrade (temperature of the laboratory). By considering each of the parameters being constant under the optimum condition, changes of the two other parameters were determined according to the Figure 6 to 9 and the effect of each factor of the tests were analyzed by the help of the related curves. Figure 3 illustrates that by increasing flow rate, the power output will increase. Increasing the linear rate of flowed water on the membrane surface reduce the effect of the concentration polarization phenomena on the membrane surface that is a hindrance to energy generation. As observed above, by rising flow rate from 10 mL/min to 40mL/min, the power output also increases and the growth of intensity of power output is reduced by continuing this trend in flow rate.

Conclusion

Power generation from salinity gradient has been considered and evaluated currently. In this study the Reverse Electro-Dialysis method has been investigated as an applicable process and the best operational conditions were determined by lab scale pilot and Taguchi method. Our results showed that this process is a reliable method in order to generate power from salinity gradient and can be applicable in industrial dessalination plants.

Keywords: ion exchange membranes, power generation, reverse electro-dialysis method, salinity gradient.