Blue Energy

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Abstract

Blue Energy is a new way to generate power from the mixing of fresh and salt water. More specific, any solution with different anion and cation concentrations can be used, but in order to the lack of resources, the mixing of fresh and salt water is the most profitable solution until now. Moreover, the natural abundance of fresh water near salt water can be used as a benefit in this new way of generating power.

Nowadays some different methods are applied in order to generate Blue Energy. Within this abstract only one way will be described: Reversed Electrodialysis (RED). In this specific way of generating power, two different kinds of membranes are used in order to create a transport of positive and negative charges. A cationic membrane is used alternately with an anionic membrane. This causes the positive ions to move in one direction and the negative ions in the opposite direction. Therefore there will be a charge at outside of the cell containing the membranes. When these charges get in contact with an electrolyte, a redox reaction will be the result. When the two sides of the cell are connected with a metal wire, an electric current will be the result because of the electron transport through the wire.

Earlier the influence of the ion types and the number of membranes has been investigated. Within the scope of the 2016 research, the influence of the membrane surface will be determined.

Keywords

Blue Energy, Reverse Electro Dialysis, membrane technology, membrane surface, sustainable energy

Introduction

In the past couple of years the emphasis of generating energy in a sustainable way has increased in The Netherlands. In 2000 the share of generating energy in a sustainable way was 2.65 %. This has increased to 11.11% in 2015 [1]. One of the projects that contribute to the increase of sustainable energy is Blue Energy. Recently, the REDstack company opened a Blue Energy Power Plant (BEPP) at the Afsluitdijk, where energy will be generated using the concept of Blue Energy [2]. In short, Blue Energy is a way to generate sustainable energy by mixing fresh water and salt water. When fresh water and salt water flow in separately and then let them go through selective ion exchange membranes, there will be a charge on both sides of the membranes. As the charges are in contact with an electrolyte, a redox reaction is the result. When both sides are connected with a metal wire, an electron transport will arise and in this way energy will be generated.

The salt water that is used for this project originates from the sea. However, other types of salt water could also be useful, such as waste water [3].

When the water passes through the membranes, the fresh water and salt water will mix resulting in brackish water, the only waste product of BEPP. This waste can be pumped back into the sea. This won't harm any ecosystems, eventually the fresh water supplying river ends up in the sea anyway.

Within previous research projects the influence of different amounts of membranes within one stack is determined. From this research was concluded that an increasing amount of membranes increased the output power of the laboratory scale BEPP. However, this could be the result of an increasing total surface area of the membrane instead of the amount of membranes. Within this research the total membrane surface will be related to the output power.

Method

Blue energy uses the difference of salt-concentration between two different solutions to create an electric current [4]. Mostly, a solution is used that contains almost no ions, like demineralised water in a laboratory environment and fresh water in real environments. The other solution often contains a lot of ions and has a high salt-concentration, like sea water. To make things easy the solutions will be called fresh- and saltwater from now on.

There are different ways to generate energy, using the concept of Blue Energy. The used technique is called: Reverse Electro Dialysis (RED). In contrast to other techniques, RED does not need mechanical parts to generate electricity, except pumps to pump the fresh- and saltwater through compartments and a pump to circulate the electrolyte. The compartments in figure 1 are separated by membranes. Those membranes are not all the same.

There are two different membranes: anion exchange membranes (AEM) and cation exchange membranes (CEM). AEM only allows negative ions through and CEM only the positive ions. Water will not pass through the membranes. In **Fout! Verwijzingsbron niet gevonden.** you can see that the positive ions will transport to the right and the negative ions to the left. Eventually a positive current will arise to the right.

Finally, this ionic current needs to be converted into an electric current. This occurs at the electrodes at both sides. The ionic current causes a redox reaction between Fe^{2+} and Fe^{3+} -ions. These reactions create the electric current. After this process the fresh- and saltwater will be mixed and come out of the compartments as brackish water.

In order to investigate the source of the actual power difference with different amounts of membranes, literature will be investigated. In a later research stadium the theory will be tested by redoing the experiments of earlier research with different amounts of membranes, but with larger membranes to increase the surface.

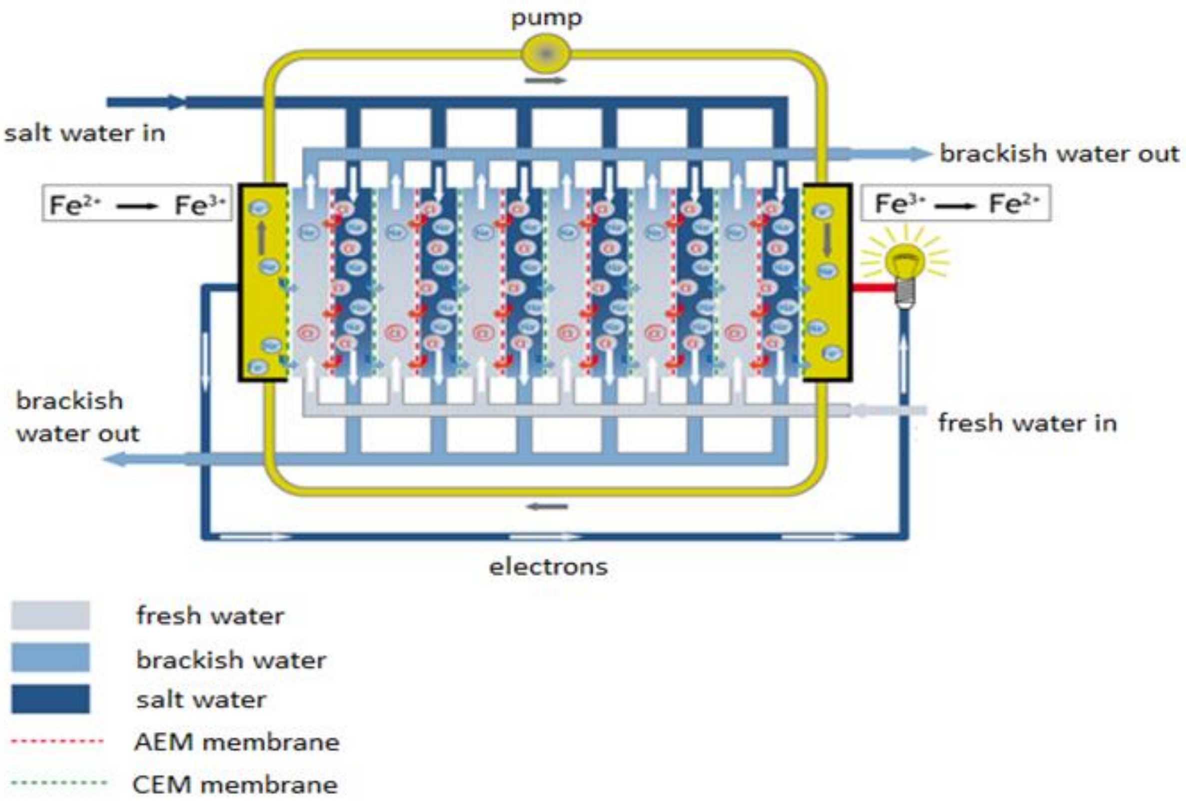

Figure 1: Schematic view of the BEPP via RED principle.

Results

Under standard conditions the standard cell potential can be calculated by equation 1, with V as standard potentials in volt:

$$V = V_{OX} - V_{RED} \quad \text{(eq.1)}$$

Under non-standard conditions the Nernst equation should be used in its simplified form at 298 K with the given concentration of the oxidizing agent and reducing agent [5]:

$$V = V_0 + \frac{0.0592}{n} \log \frac{[OX]}{[RED]} \quad \text{(eq. 2)}$$

As stated before the reaction that takes place is the conversion of Fe^{2+} ions into Fe^{3+} ions and backwars, so the cell potential of the BEPP is not actually driven by the redox reaction itself, but the transport of charge through the membranes.

Therfore, the Nernst equation should be adopted to this system. In order to do this, every membrane need to be viewd as a electrochmical cell. For a CEM the Nerst equation become [4, 6]:

$$V_{membrane} = 0{,}0592 \log \frac{[Na^+]_{salt}}{[Na^+]_{fresh}} \quad \text{(eq. 3)}$$

For the outer membranes there is is slight difference. These membranes are not enclosed by a flow of fresh water and a flow of salt water.

The left membrane in figure 1 is enclosed between fresh water and the electrolyte and the right one is enclosed between the electrolyte and salt water.

Therefore these membranes together need to be counted as one membrane. This can be written as in equation 4.

$$V = 0{,}0592 \log \frac{[Na^+]_{electrolyte}}{[Na^+]_{fresh}} + 0{,}0592 \log \frac{[Na^+]_{electrolyte}}{[Na^+]_{fresh}} = 0{,}0592 \log \frac{[Na^+]_{salt}}{[Na^+]_{electrolyte}} \quad \text{(eq. 4)}$$

Just like batteries in a serial cirquit, the stack voltage is the sum of the single membrane voltages.

From this we can conclude that the numer of membranes causes te output voltage.

This can also be described in an equation:

$$OCV = (N - 1) \cdot V_{membrane} \quad \text{(eq. 5)}$$

In the formula OCV is the ‘open cirquit voltage’, in other words, the output voltage of the whole stack with N membranes, not connected to any power consuming device.

When any power consuming device (or other component) is connected to the BEPP, the OCV value will drop because of the internal resistant of the system, caused by the ions that are forced to the poles of the BEPP and the external resistant caused by the wiring and power consuming devices This can be described in an adapted version of Ohm’s law:

$$U = I \cdot R_{ext} = OCV - (I \cdot R_{int}) \quad \text{(eq. 6)}$$

Within this equation *I* can be written as follows:

$$I = \frac{OCV}{R_{ext} + R_{int}} \quad \text{(eq. 7)}$$

Combining the two equations into an expression for the output power:

$$P = U \cdot I = I^2 \cdot R_{ext} = \left(\frac{OCV}{R_{ext} + R_{int}}\right)^2 \cdot R_{ext} \quad \text{(eq. 8)}$$

Since the resistance of the membranes is determined by the material where they are made of, the thickness of the membrane and the membrane surface, the output power of the BEPP will be different with different surface areas of the membranes [6].

This leads to the conclusion that within the experiments with different amounts of larger membranes would have similar output voltages as the same BEPP with smaller membranes.

The main difference will be that the larger membranes will generate a higher output power. This will be proven in the next step of this research..

References

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