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Concept for energy harvesting from the salinity gradient on the basis of geothermal water

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Abstract

The use of renewable energy resource is usually directed to solar, wind or hydroelectric stations. However, there are other sources for getting the 'green energy'. One of them is geothermal source, the energy stored in the underground fluids. In the world, geothermal water is used mostly for heating purposes, greenhouses, agriculture, for generation of warm water, therapeutic and recreational purposes and to generate electricity in power stations. After these uses, geothermal water is usually seen as waste water. This research presents the idea for innovative energy harvesting from the salinity gradient on the basis of waste geothermal water. Two methods are analyzed to be used: capacitive mixing (CAPMIX) and reverse electrodialysis (RED). The aim of the research concept is analysis for testing the applicability of both methods in energy harvesting from mixing of saline geothermal water and RO brine with water, before its re-injection to underground reservoirs.

Keywords: geothermal water; salinity gradient; energy; reverse electrodialysis; capacitive mixing

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1. Introduction

Limited resources of the water and energy are two key scientific problems and a challenge for the 21st century. The use of renewable energy resource in particular cases is directed to solar, wind or hydroelectric stations. However, another source for getting the 'green energy' is geothermal energy, the energy stored in underground reservoirs. In the world, geothermal water, as a carrier of geothermal energy, is used mostly for electricity production in power stations (in zones reserves of water/steam of temperatures over 150^{o}C), for heating purposes, greenhouses, agriculture, generation of warm water, therapeutic and recreational purposes.

Especially, favourable conditions for the high-temperature geothermal sources occur within the crustal plates, in rifts and in subduction zones [1]. Rifts are sites where hot magma ascends from the mantle of the Earth. In subduction zones, the crust is generated along with intensive tectonic movements and volcanism. Geothermal potential of active plate boundaries such as in Turkey is directly related to anomalous heat flow caused by intensive magmatism and volcanism [2].

Generally, the temperature increases with depth, and therefore geothermal resources may be found also in regions with a normal or also slightly above normal geothermal gradient. In the first case geothermal systems, e.g. the ones in Poland can be characterized by low temperatures (low-enthalpy), usually not higher than 100 °C. Low-enthalpy systems are more common and cover much larger areas in the World in contrast to high-temperature reservoirs.

2. Problem identification and basic principle

Concept for energy harvesting from the salinity gradient on the basis of geothermal water refers to the use of waste geothermal water, cooled in classical geothermal systems. This proposal focused on energy recovery from low-temperature geothermal water that appears in project partner countries, Poland and Turkey.

The project focuses on integrated management of waste geothermal water brine from the geo-stations. For this, the use of two innovative approaches will be considered. First, efficiency of hybrid systems for removal of such toxic elements like boron and arsenic from waste geothermal water brine will be evaluated. Hybrid systems are based on the use of fine particles of selective sorbents that can bound the target components. Then, the sorbents are concentrated during the membrane filtration, regenerated and used again. The efficiency of the hybrid system is higher than fixed bed operation as it works with a high sorption rate to adsorb the target elements.

The second innovative approach is related to energy harvesting from the salinity gradient. Two methods will be used: capacitive mixing (CAPMIX) and reverse electrodialysis (RED). Both of them are based on transportation of ions and can extract 50-85% of total energy from salinity gradient. The first process, based on RED, is now being commercialized for mixing seawater and river water, while the second one, based on the use of super- capacitors, is still under development. The aim of the project is to test applicability of both methods in energy harvesting from mixing of saline geothermal water/or RO concentrate with water, before its re-injection to the reservoir.

One should be noticed that efficient and sustainable management of different kind of resources, especially primarily energy resources, and increasing the use of renewable sources of energy are the goals

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of all European Union Partners in the era of the fight against global warming. Owing to the legal environment and the objectives related to improving the quality of surface waters set out in the Water Framework Directive, European Union are gradually limiting the utilization by-products, of so-called “open-loop” or “pump and dump” geothermal systems.

3. Methodology

RED and CAPMIX methods are based on mixing two solutions with low and high salinity and allow to convert Gibbs mixing energy into electricity [3]. In the case of RED system, the point is to use alternately organized ion-exchange membranes and pump both solutions between them. In the case of CAPMIX system, water is pumped sequentially between two carbon super-capacitors: saline and non-saline solutions [4]. In our research project, possibility to remove most toxic microelements from used geothermal water, arsenic and boron will be evaluated by newly developed sorption-membrane filtration hybrid systems.

4. Concept analysis

Geothermal energy is classified as a renewable energy source due to the fact that the heat from an active reservoir is continuously restored by natural heat of surrounding hot regions and the extracted geothermal fluids are replaced by natural recharge and by injection of the cooled fluids [5]. According to Geothermal Energy Association, there are about 12,000 MW of energy in the pipeline and about 30,000 MW resources are still under development [6]. The use of geothermal water has been well-developed in Turkey and it is in progress in Poland. Turkey is being considered as the ninth country with the access to geothermal resources while Poland tries to rationally manage its limited sources. For that reason, the integrated management of geothermal water seems to be critical for both in Poland and in Turkey. On the basis of these two cases, the result of the research could be implemented in other fields, in similar conditions regions in the world.

The thermal energy obtained from low-temperature geothermal water is mostly used for heating purposes in both countries participating in the project. As an example of Turkish side, heating the residential areas of Balçova-Izmir region by geothermal heating centre located in Izmir can be considered. The Balçova geothermal area is located in a densely populated field which makes direct distribution of heat very efficient and economical. Geothermal heat from the Balçova is utilized for greenhouse heating, balneology and residential heating. Among these targets, the latter one is the main application throughout the Balçova District Heating System. The Polish partner could illustrate that case by heating of Podhale region which is the largest geothermal field in Europe for its total geothermal capacity and heat production [7]. The geothermal water used in these regions carries thermal energy and after its receiving water turns to problematic effluent that cannot be managed fully. In both described places, the use of geothermal water for medical treatment in spa bathing centres is rather marginal and cannot be considered as the general solution. Besides that, water from these centres still needs management and it cannot be discharged into surface waters.

The objective of this project is to clean geothermal water before discharging it to reservoir or to surface water and also extraction of energy created by mixing of effluents with various salinities.

Jia et al. [8] concluded that “*Salinity energy stored as the salinity difference between saline and freshwater is a large-scale renewable resource that can be harvested and converted to electricity*”.

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However, extracting it efficiently as a form of useful energy still remains a challenge. Taking into account the development of water treatment technologies, especially membrane-based technologies for energy extraction from saline water, huge development has been seen in recent years.

The salinity of geothermal waters changes in a wide range. In some cases, a high mineralised water (with TDS of 120 g/L) is extracted, but also water containing TDS of 1-3 g/L can be also obtained. All geothermal fluids may contain high levels of such toxic elements as arsenic, mercury, lead, cadmium, iron, zinc, manganese and boron. If the used brine is released into surface aquifers, these elements can damage aquatic life [5, 9]. In order to remove these toxic elements from geothermal water, RO process is sometimes employed [10, 11]. However, RO process results in discharge of concentrate brine that can be considered from one side as a waste stream but on another side as source of salinity gradient energy (SGE). The methods of the removal of toxic elements from geothermal water are well described in two books edited by Kabay et al. 2015 [12] and Bryjak et al. 2016 [13].

In this concept, the sorption-membrane filtration method is analysed to be used for elimination of toxic elements (arsenic and boron) from waste geothermal water brine [14]. This innovative method allows extraction of some species from a dilute solution and it has been intensively studied for the last several years by Urbano et al. 2014 [15], Guler et al. 2013 [16], Kabay et al. 2009 [17], Wolska et al. 2011 [18].

The point of using hybrid system to remove specific substances is based on the fact that adsorbent particles having some binding sites can adsorb target unwanted substances from water and in next step, particles with adsorbed species can be easily separated through the membrane filtration. After filtration, the separated species are eluted in the regeneration step, and the adsorbent particles can be reused again for the next sorption step. Such process allows removal of some target species that can appear in the solution even in trace quantities. The combination of the advanced adsorbent materials with their separation on membranes reveals many advantages comparing to those of the conventionally used fixed bed adsorption systems. The main benefits of the sorption based hybrid processes are the high separation efficiency and low operational cost. There are many publications on the use of boron and arsenic sorbents by Kabay et al. 2015 [12], Bryjak et al. 2016 [13]. In addition, some papers deal with the use of hybrid system [16-18].

In harvesting salinity gradient energy (SGE), there are three main methods to explore this renewable energy*:* reverse electrodialysis (RED), capacitive mixing (CAPMIX) and pressure retarded osmosis (PRO). In the case of RED system, the studies published are mostly limited to the bench-top scale tests.

RED technology shown in Fig. 1 has passed its 50 kW pilot test and now REDstack company together with the project partners has up-scaled it located at Afsluitdijk between Ijsselmeer and Wadden Sea in the Netherlands [3, 4, 19]. CAPMIX technology depicted in Fig. 2 is still under development stage and some new findings have been announced lately [20-22]. The most important issue is to establish a method for carbon electrode coating and formation of Donnan potential between electrodes, reducing the request for preliminary charging the CAPMIX stack. There are two approaches: to cover electrodes with cation and anion exchange membranes or to deposit polycations and polyanions on their surfaces. The resistances of such layers are critical for a long time action of the CAPMIX system.

Some larger RED stacks were described and their data can be found occasionally [4]. The RED system is composed of repetitive assembly of cation and anion exchange membranes and between them salty and

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fresh water are pumped (Fig. 1). The generated ionic current is converted to electrical current by a redox couple at the electrodes. So far, the conducted studies on the design of RED unit have compromised mostly membrane design that provides higher power densities. System restrictions due to the increase of the compartments number related to stack design should also be taken into account as well as the type of the waters to be used, type of membranes to be employed, geometry of spacers and other process parameters. These parameters will be also evaluated in the present project.

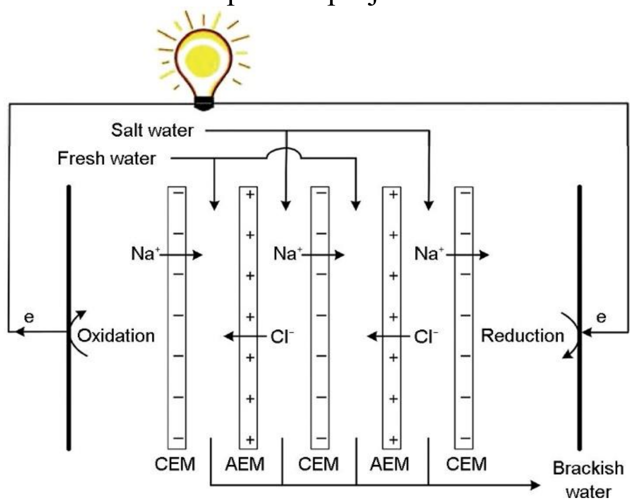

Fig. 1 Principle of reverse electrodialysis (RED) (after [23])

The second approach for collecting the salinity gradient energy is related to the use of CAPMIX system (Fig. 2). The system, although has not been fully explored, based on changing the salinity of solutions in contact with large surface area of electrodes.

Two CAPMIX technologies have been developed: Capacity energy production by Double Layer Expansion, CDLE, and Capacitive energy production by Donnan Potential, CDP [21]. The first needs electrodes to be charged before immersion into saline water while the second applies spontaneous charge created on the surface ion-exchange membranes or polyelectrolytes. The recently published papers on the efficiency of power production showed that CDLE system was able to give 10-20 mW/m^2 while CDP offered 100-300 mW/m^2 [21].

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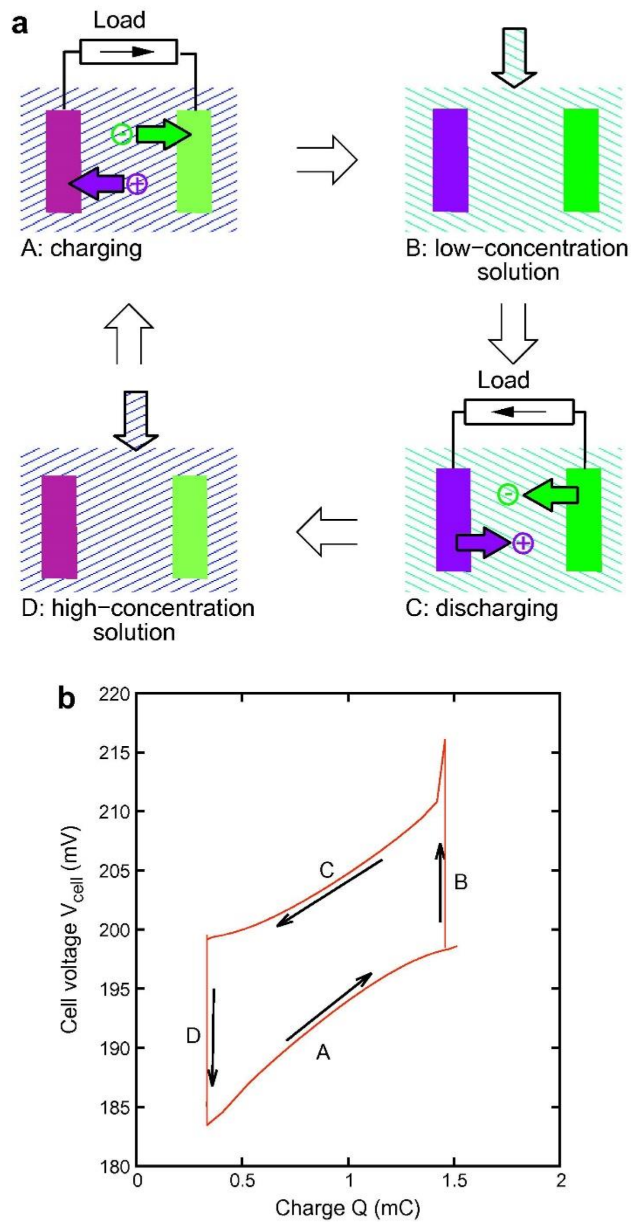

Fig. 2 Principle of capacitive mixing (CAPMIX) – method for energy extraction from salinity gradient. Part a: the cycle characteristic. Part b: the cycle presentation" the voltage versus charge graph. A - charging; B - flow of low-salinity solution; C - discharging; D - flow of high-salinity solution (after [24])

The above calculations were made for mixing seawater with fresh water. Neither geothermal water nor RO brine were compared for generation of energy by these two methods. Among the CAPMIX systems, the more efficient seems to be CDP as for CDLE the experimentally extracted energy was significantly lower than predicted value. The reason for that was existence of current leakage, limited wettability of electrode or in homogeneity of the surface of activated carbon. These obstacles were limited for CDP system, when ion exchange membrane covered the electrode. However, preparation of electrode-membrane assembly becomes a piece of the art. Hence, the careful coating of electrode with ion-permeable

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barrier seems to be critical for optimization of CDP system [22]. That will be the first goal of our studies with CAPMIX system. The second goal is related to assemble the CAPMIX cells. It is proved in recent publication that energy efficiency of the system can be improved by organizing the cells in series [21]. When number of cells was increased by one, the energy efficiency raised 1.5-1.6 times. Hence, it will be interesting to see how many cells should be used to create the CDP-CAPMIX stack that 'produces' reasonable amount of energy.

The general aim of the concept is to suggest an integrated management of geothermal water withdrawn from the geothermal wells. Thus, it will be possible to re-inject the geothermal brine safely after extraction of its thermal energy followed by RO treatment for elimination of toxic elements. It will be also possible to produce energy from salinity gradient before discharging of the waste brine of RO process and/or re-injecting geothermal water after its energy is utilized. Such integrated treatment of geothermal water can be considered as the environmentally benign technology as it limits the amount of harmful constituents and allows extraction of additional portion of energy from geothermal water/RO brine salinity. The results of the tests will be evaluated in terms of energy efficiency, environmental and also economical aspects. The aim of the research will be also the estimation of the possibility for implementation of the results in the context of their use in industrial scale process. The results of the research will be published soon.

6. Conclusions

The technological excellence of the project is related to the integrated management of the waste brine after recovery of thermal energy in the geothermal heating centres. The conducted utilization of such water sources should offer clean water for irrigation purposes and fresh water production, as well as saving surface waters and underground aquifers against their additional contamination and making it possible to gather the additional portion of energy from mixing solutions with various salinity. Such innovative approach will open new perspectives for development of environmentally benign mining technologies. What is more, the methods for energy recovery from the salinity gradient are counted to the group of the distributed sources of renewable energy that will be added to the global grid of electric network in the nearest future.

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References

[1] Hajto, M., Sowiżdżał, A. (2018) A global assessment of geothermal resources. In: Geothermal Water Management (Eds: J. Bundschuh, B. Tomaszewska). CRC Press. Taylor & Francis Group, vol. 6. , 3-29

[2] Dickson, M.H, Fanelli, M. (2004) What is geothermal energy? International Geothermal Association. Available from: https://www.geothermal-energy.org/what_is_geothermal_energy.html [accessed April 2018].

[3] Kempener, R., Neumann, F. (2014) Salinity gradient energy, technology brief. Available from: www.irena.org [accessed April 2018].

[4] Guler, E. (2014) Anion exchange membrane design for reverse electrodialysis. PhD dissertation, University of Twente, January 2014, Enschede, The Netherlands

[5] Goldstein, B., Hiriart, G.G. (2011) Geothermal Energy. In: Reneavable Energy Source And Climate Change Mitigation (Editor: O. Edenhofen) C. 4, 401 – 436

[6] Matek, B. (2014) Annual U.S. & Global geothermal power production report. Geothermal Energy Association (April 2014) 8-13. Available from: http://geo-energy.org/events/2014%20Annual%20US%20&%20Global%20Geothermal%20Power%20Production%20Report%20Final.pdf. [accessed April 2018].

[7] Kepinska, B. (2015) Geothermal Energy Country Update Report from Poland, 2010-2014. Proceedings World Geothermal Congress-2015, Melbourne, Australia, 19-25 April 2015.

[8] Jia, Z., Wang, B., Song, S., Fan, Y. (2014) Blue energy: Current technologies for sustainable power generation from water salinity gradient. Renewable and Sustainable Energy Reviews 31, 91–100.

[9] Tomaszewska, B., Szczepański, A. (2014) Possibilities for the efficient utilization of spent geothermal waters. Environ. Sci. Pollut. Res. 21, 11409-11417.

[10] Tomaszewska, B., Pajak, L. Bodzek, M. (2014) Application of hybrid UF-RO process to geothermal water desalination. Concentrate disposal and cost analysis. Arch. Environ. Prot., 40,137-151

[11] Samatya, S., Tuncel, A., Kabay, N. (2015) Boron removal from RO permeate of geothermal water by monodisperse poly(vinylbenzyl chloride-co-divinylbenzene) beads containing N-methyl-D-glucamine. Desalination 364, 375–381

[12] Kabay, N., Bryjak, M., Hilal, N. (2015) Boron Separation Processes. Elsevier, Amsterdam

[13] Bryjak, M., Kabay, N., Rivas, B., Bundschuh, J. (2016) Innovative Materials and Methods for Water Treatment. CRC Press, Amsterdam

https://doi.org/10.32438/WPE.6118

[14] Kabay, N., Bryjak, M. (2013) Hybrid processes combining sorption and membrane filtration. In: Encyclopedia of Membrane Science and Technology (Eds. E.M.V.Hoek, V.V.Tarabara), John Wiley & Sons, Chichester.

[15] Urbano, B., Paredes, J., Rivas, B., Kusku, Ö., Kabay, N., Bryjak, M. (2014) "Water-insoluble copolymer based on N-methyl-d-glucamine and quaternary ammonium groups with capability to remove arsenic", Environ. Prog. Sustain. Energy., 33, 1187-1193.

[16] Guler, E., Kabay, N., Yuksel, M., Yiğit, N.O., Kitiş, M., Bryjak, M. (2013) Integrated solution for boron removal from seawater using RO process and sorption-membrane filtration hybrid method. J.Membr.Sci., 375, 249-257

[17] Kabay, N., Yilmaz-Ipek, I., Soroko,I., Makowski, M., Krmizisakal, O., Yag, S., Bryjak, M., Yuksel, M. (2009) Removal of boron from Balcova geothermal water by ion exchange-microfiltration hybrid process", Desalination 24, 167-173

[18] Wolska, J., Bryjak, M. (2011) Preparation of polymeric microspheres for removal of boron by means of sorption-membrane filtration hybrid. Desalination 283, 193–197

[19] Guler, E., Nijmeijer, K. (2018) Reverse electrodialysis for Salinity Gradient Generation: Challenges and Future Perspectives. Journak of membrane Science&Research 4 (3), 108-110

[20] Bijmans, M., Burheim, O., Bryjak, M., Delgado, A., Hack, P., Mantegazza, F., Tenisson, S., Hamelers, H. (2012) Capmix-deploying capacitors for salt gradient power extraction. Energy Procedia 20 108–115

[21] Iglesias, G., Ahualli, S., Fernandez, M., Jimenez, M., Delgado, A. (2016) Stacking of capacitive cells for electrical energy production by salinity exchange. J.Power Sources 318, 283-290

[22] Fernandez, M., Wagterveld, R., Ahualli, S., Liu, F., Delgado, A., Hamelers, H. (2016) Polyelectrolyte-vs. membrane-coated electrodes for energy production by capmix salinity exchange methods. J.Power Sources 302, 387-393

[23] Vermaas, D.A., Guler, E., Saakes, M., Nijmeijer, K. (2012) Energy Procedia 20, 170-184

[24] Brogioli, D., Ziano, R., Rica, R.A., Salerno, D., Mantegazza, F. (2013) Capacitive mixing for the extraction of energy from salinity differences: Survey of experimental results and electrochemical models. Journal of Colloid and Interface Science 407, 457-466.

https://doi.org/10.32438/WPE.6118