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Perspectives of Geothermal Water Concentrates Reuse in Different Directions in Poland, Also in the Balneology and Cosmetology Industry

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ABSTRACT

In past decade, the growing use of geothermal water in inland regions, mainly for heating, power generating, bathing and recreation purposes, is associated with the intensification of geothermal research. This research is oriented towards optimizing and improving the efficiency of processes and focused on the development of new technologies and methods enabling comprehensive and multi-variant management of these waters. Some of the spent geothermal water is used for various direct uses including district heating, bathing, and swimming. The extra water is dumped, mainly into surface waterways or is re-injected into geological formations depending on the water salinity and physio-chemical properties. In order to increase effectiveness of geothermal water utilization and decrease the shortfall of ordinary water in many regions of the world, the desalination plants are designed. Cascade utilization of geothermal water resources ensure its sustainable management and increase effectiveness of the geothermal plant. Worldwide, membrane processes are well-known desalination technologies applied for providing fresh water, and also simultaneously production of geothermal waters concentrates. Concentrates are normally considered as waste and depending on its properties, are dumped into surface waterways, re-injected into geological formations or are directed to evaporation ponds. However, to expand the cascade utilization of geothermal sources, concentrates are to be considered as a valuable source for production mineral solutions and salts or chemicals for various branch of industry, including balneology and cosmetology industry. The research filed incudes new areas for utilization of geothermal waters in the Poland area, and presents the possibilities for reuse of geothermal water concentrates, gained from desalination processes, in the balneology and cosmetology industry.

1. INTRODUCTION

Considering the hydrological conditions and the geographical location of the country within the range of temperate transitional climate, the water resources in Poland are small. They are also characterized by a significant spatial diversity, which is a consequence of the high variability of natural environmental conditions which shape the hydrological cycle. In Poland, water per capita is about 1800 m^3/year, during a drought this indicator falls below 1000 m^3/year/person. Taking this indicator into consideration, Poland is in the group of countries threatened with water deficit. The average amount of water per capita in Europe is 2.5 times greater, about 4500 m^3/year. Analyzing the annual availability of clean water for Europe, it can be seen that in the Central and Eastern European areas, including Poland and Spain, have on average less than 200 mm of fresh water available each year, while currently water demand is 3-10 times higher (Gutry-Korycka, 2018). At the same time, the use of geothermal energy in Europe and the world has increased significantly in recent years, including inland regions, mainly for heating, power generating, bathing and recreation purposes. This phenomenon is associated with the intensification of research oriented towards optimizing and improving the efficiency of processes and development of new technologies/methods which enable comprehensive and multi-variant management of these waters (Le et al. 2019). In Poland, the usage of geothermal resources is insufficient considering the amount of potential geothermal energy that exists (Sowiżdżał, 2018). The spent geothermal water is used for various direct uses including district heating, bathing, swimming. The extra spent water is dumped, mainly into surface waterways or is re-injected into geological formations depending on the salinity and physico-chemical properties (Tomaszewska and Szczepański, 2014). In order to increase the effectiveness of geothermal water utilization in many regions around the world, the geothermal water desalination plants are designed to integrate other beneficial processes for securing high-quality drinking water, obtaining good quality new products, and limiting the negative impact on the environment (from dumping geothermal water into surface waterways). Membrane processes, including nanofiltration and reverse osmosis, are commonly worldwide used for desalination to provide fresh water, at the same time additional geothermal water concentrate is produced. Concentrates, also called as brines or retentates, are conventionally considered as wastes. The by-products of the production of drinking water and are injected back into the aquifer or are disposed in other several ways, including evaporation ponds and land application (Tyszer and Tomaszewska, 2019). Depending on the physio-chemical parameters, concentrates obtained from desalination of geothermal waters may also be considered as useful products, e.g. for therapeutic purposes, balneology, in the cosmetics industry and in baths (Tomaszewska and Dendys, 2018).

2. GEOTHERMAL WATERS IN POLAND

In Poland, where space heating is a key sector in geothermal water utilization, entrepreneurs are more inclined to implement solutions in the discharging of used geothermal waters into streams or drain systems, provided that the quality of wastewater meets legal requirements (Kępińska, 2018). In other cases, the water is injected into the aquifers from which it was drawn. However, this method is expensive and there is a high probability of corrosion or clogging of the injection well. A more comprehensive, efficient and sustainable management of cooled geothermal waste water should be implemented in Poland. Moreover, as can be seen from Figure 1, the functioning geothermal heat plants and other centers are mainly located in the area of central and southern Poland. Therefore it is impossible to discharge both the geothermal waters used and the products after the initial treatment of these waters into the sea.

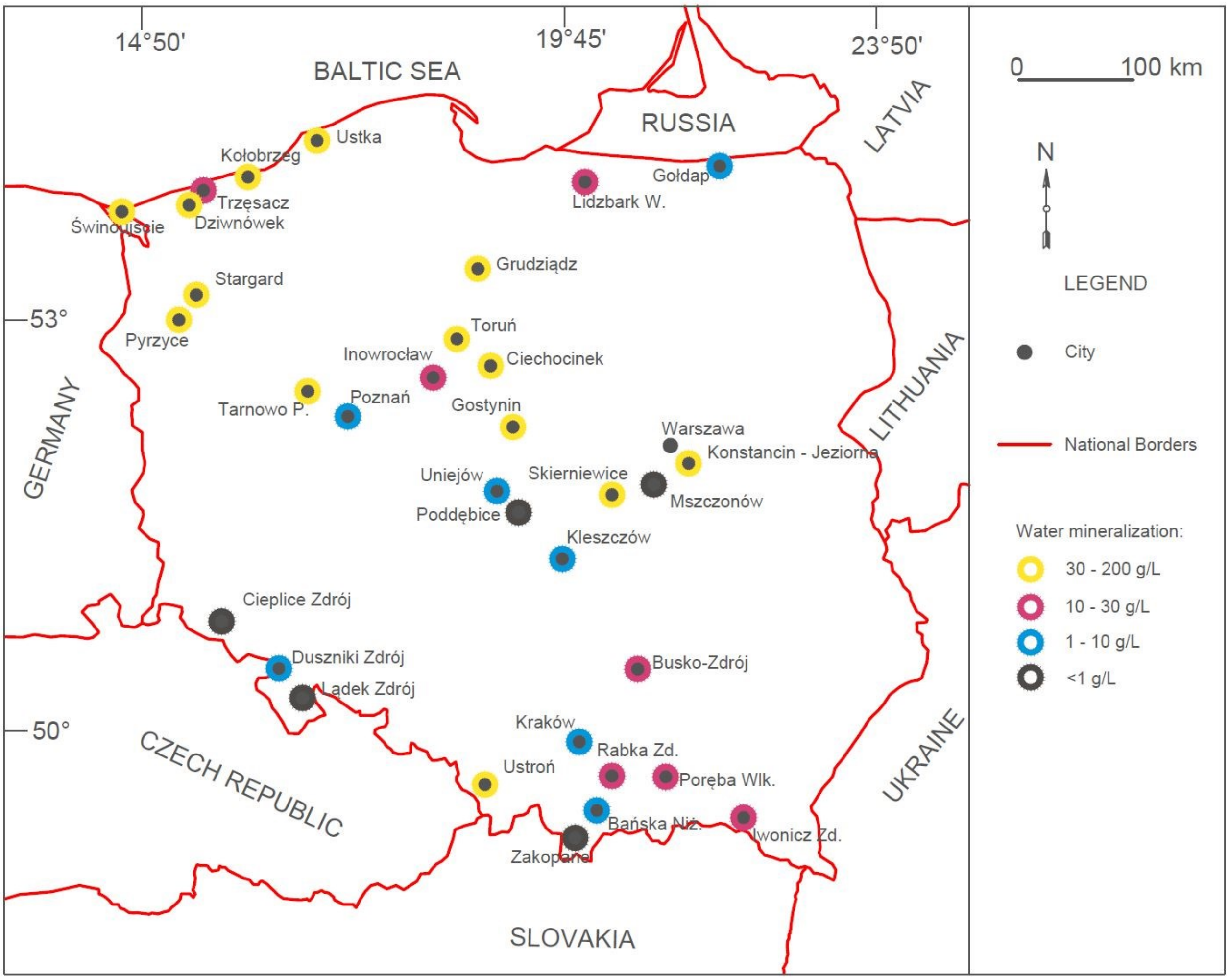

Figure 1: Water mineralization in functioning centers in Poland area.

In Poland, in physical and chemical terms, the geothermal waters present in the structures exhibit different properties. There is freshwater, in which total dissolved solids (TDS) are below 1.0 g/L, brackish water (TDS from 1 to 10 g/L), saline water (TDS from 10 to 30 g/L) and brine (TDS more than 30 g/L) (Figure 1). Brine and saline geothermal water are mostly used for heating purposes, on the other hand geothermal waters with low mineral content and freshwater are mainly made available for both heating and leisure purposes (Tomaszewska and Szczepański, 2014). Managing geothermal waters used for different purposes and the placement of geothermal plants is a challenge. The use of membrane processes to purify/desalinate this water can significantly reduce the negative environmental impact of discharged waste, cooled geothermal water into watercourses or sewage, reduce cost and problem with re-injection of lot amounts of spent geothermal waters into wells, as well as improve the efficiency of their use.

3. CONCENTRATE UTILIZATION – WORLD EXPERIENCE

Membrane processes, especially NF and RO processes, are filtration techniques, which are widely utilized for water desalination, potable and ultrapure water production, also used in geothermal water treatment processes and in tertiary wastewater treatment. Ease of combination with other techniques (modular construction) and a small required surface area of such installations, are the main advantages (Pérez-González et al., 2012; Quasim et al., 2019). This technology uses semipermeable membranes that separate the water stream into two: 1) permeate, which contains purified water (reduced soluble matter content) that passes through the membrane, and 2) concentrate, the part of water that does not pass through the membrane containing elevated concentrations of salts and other retained compounds (nearly all of dissolved solids) and therefore requires an appropriate and environmentally friendly management option. The second stream is becoming an important concern, especially for inland installations due to its high concentration of dissolved solids (desirable and undesirable ingredients). Currently, principle concentrate management is redirected to recovering valuable constituents or reuse (Istriokhatun et al., 2018). Tomasini et al. (2019) presented a system in which industrial wastewater was treated by MBR-RO process in order to acquire zero-brine-discharge and/or concentrate reuse. Zheng et al. (2015) proposed a novel approach for RO concentrate treating in order to reused it among others in dyeing industry. Egea et al. (2019) carried out pilot research consisting of removal of emerging contaminants from wastewater using reverse osmosis for its subsequent reuse. The preliminary results indicated that this technique achieves 100% removal of the contaminants without signs of membrane damage. Finster et al. (2015) emphasized that the value of total dissolved solids (TDS) affects the functioning of a geothermal installation and the process of its treatment after its use for energy purposes. Moreover, they underline that specific composition of treated fluid may cause major problems associated with the operation of RO and NF which are membrane fouling and scaling. Possible effective treatment and reuse of NF/RO concentrate can notably reduce cost of its disposal, mostly for inland desalination plants. Joo et al. (2015) present novel technologies for treatment RO concentrate and indicate that technologies are needed for achieving near Zero Liquid Discharge (ZLD) from RO processes. Pérez-González et al. (2012), Shanmuganathan et al. (2016) and Naidu et al. (2017) mention that proper treatment/disposal of concentrate are an important aspect of sustainable water reclamation practice and is a meaningful component of water treatment process. Moreover, poorly managed treatment and disposal of RO concentrate causes significant environmental and economic consequences. Some of geothermal waters naturally possess curative properties, they can be concentrated by membrane processes to produce a curative solution or crystalline salt used for therapeutic treatments and the cosmetic industry (Lund, 1996). The elevated concentration of dissolved elements and specific chemical compound of geothermal water concentrates can positively affect the condition of the skin and alleviate symptoms of dermatological diseases. Some of the most recognizable companies, including Avene, La Roche Posay, Vichy and Blue Lagoon, which produce cosmetics based on geothermal waters, ensure that these products have soothing, softening and calming effect on the skin, strengthen the natural protective functions of the skin and help it fight the signs of aging (Huang et al., 2018; Bacle et al., 1999).

4. POTENTIAL OF CONCENTRATE REUSE IN POLAND

As previously mentioned, in Poland space heating is a key sector for geothermal energy utilization, but there is also observed an increase in interest in the use of geothermal waters for recreational and balneological purposes. Heat plants located in Mszczonów, Uniejów and in Podhale region use geothermal waters for recreational purposes in addition to heat production. By 2016, fourteen geothermal recreational centers have been opened, seven of which operate in the Podhale region. Moreover, in Pyrzyce and Uniejów the use of geothermal water in food processing has been started. Other small-scale applications include the recovery of iodine-bromine salts and the production of cosmetics (Uniejów) (Kępińska, 2018). Geothermal waters used for heating purposes in Poland have specific physical and chemical parameters. Cooled geothermal waste waters can potentially be a source of drinking water and may have valuable ingredients, including those used in the cosmetics and balneology industries. Therefore, preliminary laboratory and semi-industrial studies were carried out using membrane processes to assess their possible further use. On a laboratory scale, tests were carried out for treatment with nanofiltration and reverse osmosis processes using the apparatus presented in Figures 2 and 3, respectively. The research was carried out with different process parameters: transmembrane pressure 10-15 bar, permeate recovery 50-75%, water temperature 21-30°C, membrane modules in ''cross-flow'' or ''dead-end'' mode and with the use of several widely available NF and RO membranes (Rajca et al., 2017; Tyszer and Tomaszewska, 2019; Tomaszewska and Tyszer, 2017).

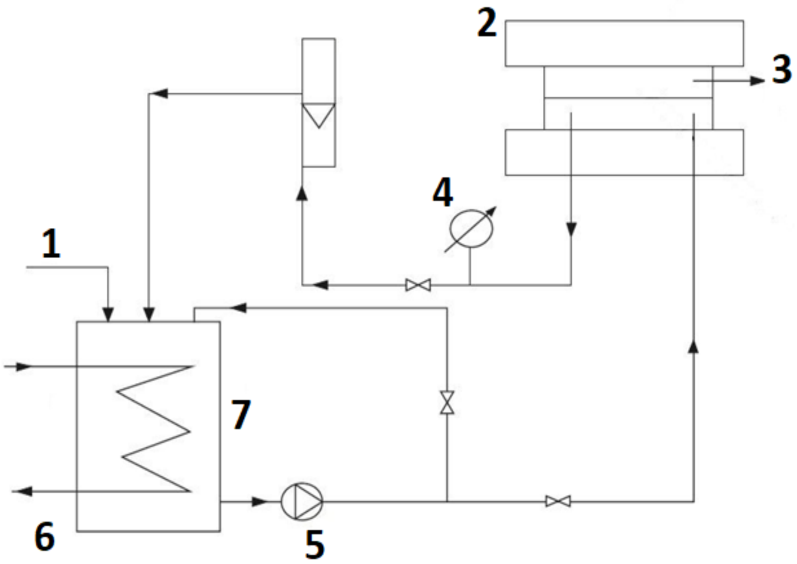

Figure 2: The diagram of apparatus used for nanofiltration and reverse osmosis tests in ''cross-flow'' mode conducted in laboratory scale on the example of geothermal waters from Poland area (1 – raw water inlet; 2 – membrane cell; 3 – permeate outlet; 4 – rotameter; 5 – pump; 6 – heat exchanger; 7 – raw water tank) (based on Rajca et al., 2017).

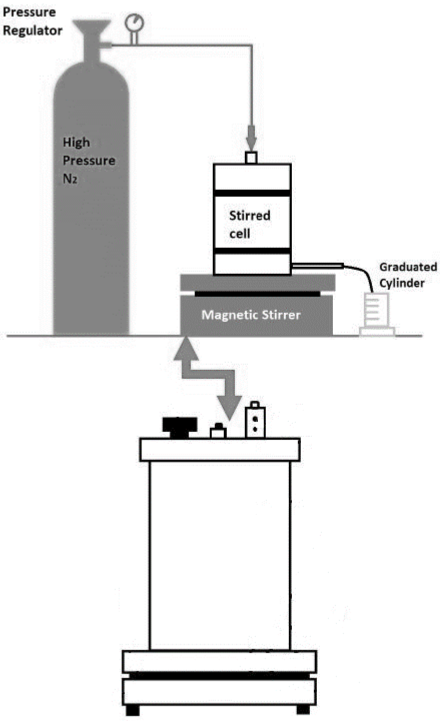

Figure 3: The scheme of geothermal water desalination apparatus applied in RO processes in ''dead-end'' mode conducted in laboratory scale on the example of geothermal waters from Poland area (based on Tyszer and Tomaszewska, 2019).

The results of the tests conducted in a laboratory, indicate that both NF and RO processes are optimistic techniques to desalinate cooled geothermal waste water for production drinking water (permeate) and solutions useful for balneology and cosmetic industry (concentrate) (Rajca et al., 2017; Tyszer and Tomaszewska, 2019; Tomaszewska and Tyszer, 2017). The results of the tests indicate that most of the concentrates obtained can potentially be used for cosmetic or balneological purposes because they meet the requirements for the content of undesirable ingredients according to the regulation of the Polish Minister of Health of 2006 (Regulation of the Polish Minister of Health, 2006). Only a few concentrates do not meet the requirements and additional removal of chromium, boron or other undesirable components is necessary due to small exceedances of the required standards. Moreover, the results of the research indicate that use of membrane processes has allowed a significant increase in the content of desirable constituents such as silica, which could potentially extend the use of these concentrates. However, previous work has stressed that further research is needed to design industrial-scale installations with the appropriate parameters to achieve the best possible concentration effects (Rajca et al., 2017; Tyszer and Tomaszewska, 2019; Tomaszewska and Tyszer, 2017). After promising research carried out on a laboratory scale, it was also decided to perform semi-industrial scale studies using previously tested membranes and process parameters. Figure 4 presents a diagram of the semi-industrial installation used for the research.

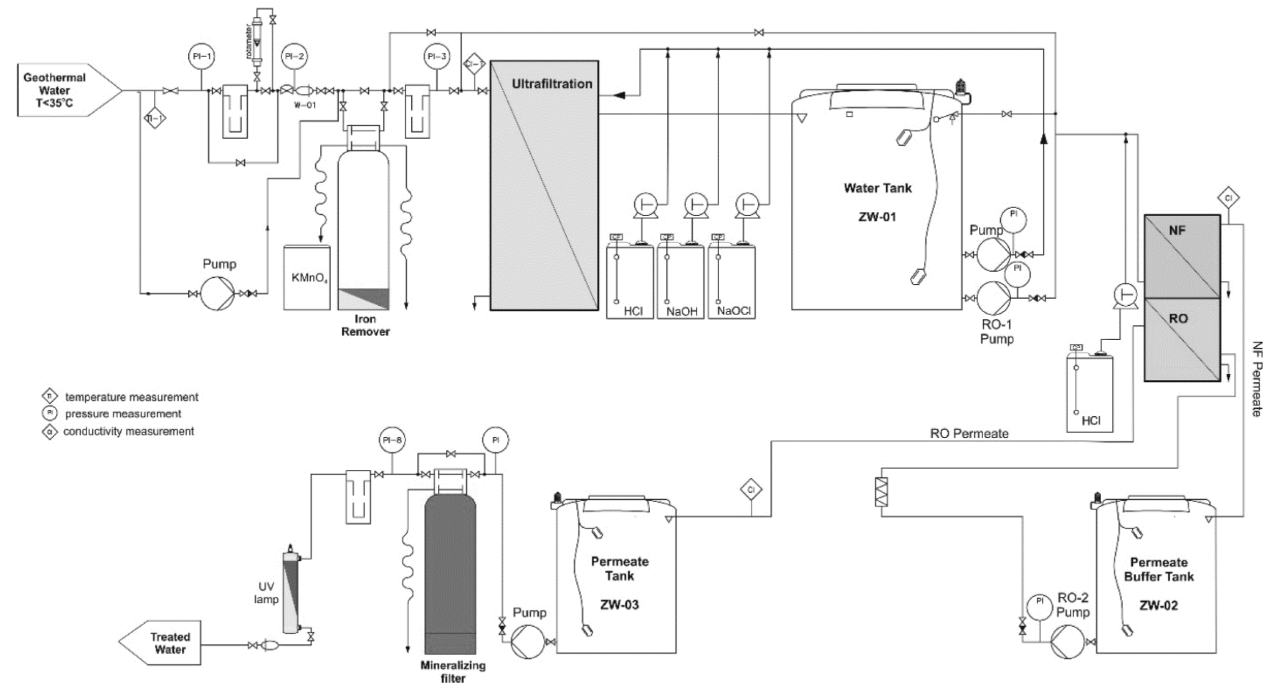

Figure 4: The scheme of semi-industrial geothermal water desalination facility located in Podhale region in Poland (based on Tomaszewska and Dendys, 2018; Tomaszewska, 2018).

Tomaszewska and Dendys (2018) showed that research conducted on a semi-industrial scale confirmed that waste geothermal water, used for heating purposes can be concentrated by membrane processes (NF/RO) and after that reused as solution valuable for balneology and cosmetic industry. The implementation of this idea on an industrial scale could improve geothermal water management and reuse. Also, it can reduce the negative impact of the discharge of saline waste geothermal water to streams (Tomaszewska and Dendys, 2018). Moreover, Bryjak et al. (2018) and Tomaszewska (2018), research from Poland and Turkey, presented the concept of alternative-indirect use of geothermal water concentrates gained from membrane processes in these countries. It consists of generation of electricity from the salinity gradient with the use of two methods: reverse electrodialysis (RED) and capacitive mixing (CAPMIX). The basic idea of both methods is that mixing two solutions with low and high (concentrate) salinity allows the Gibbs mixing energy to be extracted and converted to electricity. Using these methods it is possible to extract 50-85% of total energy from salinity gradient. The research is currently being conducted as a bilateral international project. Based on preliminary results can be concluded that the use of geothermal water concentrates as a source to generate additional amount of energy (electricity) from salinity gradient is an innovative approach which should be further established particularly in inland areas. This novel solution can improve rational and effective use of geothermal resources with support from modern technological approaches and methods.

5. CONCLUSIONS

In accordance with the global trends, preliminary research was also conducted in Poland in order to create an installation allowing to minimize the amount of concentrate obtained based on membrane processes. Also, it is an alternative to conventional re-injection of geothermal water into the aquifer, with a simultaneous production of water suitable for consumption as well as concentrate that can be a valuable solution for cosmetic or balneological purposes (depending on the adopted process parameters and the specific composition of the treated geothermal water). Membrane processes, due to their low invasiveness in the chemical composition of water, are a promising technology and can potentially be used in Poland area. Of course, in some cases, additional treatment methods should be applied to ensure that water quality meets the requirements for products that can be used for balneological purposes and in the cosmetics industry. Moreover, presented additional indirect use of geothermal water concentrates is considered as a novel approach and should be further established in order to increase the effectiveness of geothermal energy usage.

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