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Low-enthalpy geothermal energy as a source of energy and integrated freshwater production in inland areas: Technological and economic feasibility

Barbara Tomaszewska[a,b,*], Leszek Pająk[a,b], Jochen Bundschuh[c,d], Wiesław Bujakowski[a]

[a] Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Wybickiego 7 str., 31-261 Kraków, Poland
[b] AGH University of Science and Technology, Mickiewicza 30 Av., 30-059 Kraków, Poland
[c] Faculty of Health, Engineering and Sciences, University of Southern Queensland, Toowoomba, Weststreet, 4350, QLD, Australia
[d] KTH Royal Institute of Technology, Teknikringen 76, SE-10044 Stockholm, Sweden

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ABSTRACT

The paper presents an innovative approach to freshwater production using geothermal aquifers as a water and energy source. The main parameters which can potentially influence the results of the analysis were selected to investigate their effect on the proposed schemes, e.g. feed water quality, quality of the geothermal resource, concentrate utilisation and cost of freshwater production. A technical and economic feasibility study demonstrates that effective use of geothermal resources can include direct utilisation of geothermal energy in the heating system and the use of the cooled water as a source of freshwater obtained in a desalination unit. The comparison of the costs of freshwater from current freshwater resources in Poland (groundwater and surface water) with those calculated for the geothermal option showed that the costs of the latter are equal to the former. The treatment of geothermal water can bring an improved water balance for drinking purposes. In areas of high water deficit, the solution presented is a good example of the rational management of geothermal resources.

1. Introduction

Water and energy are two interconnected key scientific-technological problems of global significance. At the end of the 20th century, the deficit of water for human consumption and economic purposes forced us to focus on rational use of our resources. Therefore, increasing use of renewable energy and improving energy efficiency is a challenge for the 21st century.

It is well-known that the process for desalinating water is energy intensive and therefore involves significant power (heat, electricity) consumption and results in significant greenhouse gas emissions when fossil fuels are burnt to provide this energy using traditional technologies [1]. Nowadays, environmentally-friendly energy sources are increasingly used in order to desalinate seawater and many studies combine the desalination process, apart from the technology adopted, with renewable energy such as wind, solar, or geothermal sources [2,3]. In most cases the use of geothermal energy is analysed in classical systems (i.e. fossil-fuel powered) to provide electricity for desalination (e.g. reverse osmosis (RO) or heat to power thermally driven desalination processes, such as MSF (multi-stage flash), and MED (multi-effect distillation) or technologies still in the development stage such as MD (membrane distillation) [4].

The advantage of geothermal heat sources is that the heat transfer fluid and the desalination process feed could be derived from the same stream (feed) which is "water". These sources do not require a physical storage unit since they are stored in the aquifers below ground level and can be steadily (i.e. 24 h a day, 365 days a year) accessed to meet the process needs [5].

Goosen et al. [6] have provided a critical overview of seawater desalination using geothermal resources including assessment of the environmental risks, market potential and barriers to growth. They highlighted the point that the use of geothermal energy for thermal desalination can only be justified in the presence of easily accessible geothermal reservoirs, providing low-cost heat, which is synonymous with superficial sources. Undoubtedly, the potential and efficiency of using geothermal energy resources is directly dependent on the specific geological and hydrogeological conditions which can vary greatly worldwide.

Lack of water is a major feature of many most islands; this is also true for many inland areas in the World. There are regions where water

* Corresponding author at: Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Wybickiego 7 str., 31-261 Kraków, Poland
E-mail addresses: tomaszewska@meeri.pl, barbara.tomaszewska@agh.edu.pl (B. Tomaszewska), pajak@meeri.pl, pajakl@agh.edu.pl (L. Pająk), jochen.bundschuh@usq.edu.au (J. Bundschuh), w.bujakowski@meeri.pl (W. Bujakowski).

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Nomenclature

A, B, B_w	auxiliary coefficients [−]
a_g	temperature compensation factor for the rock medium [m^2/s]
c_b	specific heat of water [J/(kg °C)]
C_{ch}	annual cost of purchase of chemicals [€/yr]
C_{el}	annual cost of electricity consumption [€/yr]
C_{mrs}	annual cost of maintenance (eg. repairs, assumed as 2% of total investments per year) [€/yr]
C_o	current cost of injecting geothermal water into the formation without the desalination process (only taking the cost of energy carriers purchased into account) [€/yr]
c_{rc}	specific heat of rock formation [J/(kg °C)]
c_r	isothermal compressibility coefficient of rock skeleton [1/Pa]
c_s	compressibility of mineralised water [1/Pa]
c_t	compressibility of the conducting medium (active during the flow) [1/Pa]
C_t	total annual cost of water treatment [€/yr]
d	inner borehole diameter [m]
D_{ft}	fixed asset depreciation (investment expenditure spread evenly over 15 years) [€/yr]
E_{el}	amount of electricity used by pump for reinjection [J]
g	Earth's gravity [m/s^2]
h	thickness of water-bearing layer [m]
h_p	thickness of active layer [m]
H_z	level of static water table, calculated in relation to ground surface [m]
H_w	depth of borehole [m]
INV_{wt}	capital expenditure incurred for installation of water treatment [€]
k	aquifer permeability [m^2]
k_h	horizontal permeability [m^2]
k_s	permeability of zone where skin-effect occurs [m^2]
k_v	vertical aquifer permeability [m^2]
m_b	water flow rate [kg/s]
p, p'	pressure p [Pa], p'[psi]
p_{wh}	expected injection wellhead pressure [Pa] (estimated and showed on Fig. 2)
p_d	pressure on wellhead in working condition (dynamic overpressure on the well head) [Pa]
P_{el}	power consumption required by pump for treatment unit [W]
p_{tr}	required pressure of the treatment unit [Pa] (in described cases p_{tr} = 0.3 MPa)
p_{atm}	atmospheric pressure [Pa] (can be assumed as 0.1 MPa)
q_{str}	heat exchange intensity [W/m]
r_d	radius of pressure changes caused by injection [m]
r_s	cold front radius [m]
R_{tw}	income from drinking water sales [€/yr]
r_w	well radius [m]
r_{wa}	damage zone range [m]
S	salinity (percentage of substances dissolved in water by mass) [%]
S′	fraction of substances dissolved in water by mass [−]
s	mineral content of mineralised water (salinity) [mg/L] ($s = S' \rho$)
t, T, T'	temperature, t [°C], T [K], T'[°F]
t_l	injected water temperature at the liner level [°C]
t_s	injected water temperature at Earth surface [°C]
t_s	water temperature [°C]
t_∞	rock medium temperature [°C]
V_b	injected water flow rate [m^3/s] (assumed as: Case 1–255 m^3/h = 0.071 m^3/s, Case 2–261.4 m^3/h = 0.073 m^3/s, Case 3–250.8 m^3/h = 0.070 m^3/s)
w	liquid flow speed in the borehole [m/s]
Δp	total required excess pressure to be generated by injection pumps [Pa]
Δp_p	flow resistance in absorption well [Pa]
Δp_w	resistance of water injection into water bearing layer [Pa]
Δp_s	resistance connected with skin-effect, near to well liner [Pa]
ΔV_{wp}, ΔV_{wT}	auxiliary coefficients used during water density as a function of pressure and temperature estimation [−]
ϕ	effective aquifer porosity [−]
γ	Euler's constant [−]
λ	coefficient of friction [−]
λ_g	coefficient of thermal conduction through the rock medium [W/(m K)]
μ	dynamic viscosity of injected liquid [Pa s]
μ_0	dynamic viscosity of water at reservoir temperature and atmospheric pressure [Pa s]
μ_{t1}	dynamic viscosity of water at injection temperature [Pa s]
μ_{t0}	dynamic viscosity of water at natural reservoir temperature [Pa s]
η	energy efficiency of pump [−]
ρ	liquid density [kg/m^3]
ρ_r	liquid density [kg/m^3]
ρ_{av}	averaged density of liquid injected into the borehole, above the static water table [kg/m^3]
$\rho_{av\ wt}$	average density of the liquid injected into the source formation layer, in dynamic conditions (during injection), at the depth interval of H_z to H_w [kg/m^3]
$\rho_{sr\ n}$	average density of the liquid in the borehole, under steady state (natural) conditions, at the depth interval from H_z to H_w [kg/m^3]
ρ_{t1}	water density at injection temperature [kg/m^3]
ρ_{t0}	water density at natural reservoir temperature [kg/m^3]
τ, $\tau 1$, $\tau 2$	time [s], assumed time period from $\tau 1$ in beginning and $\tau 2$ in the end [s] (assumed values: $\tau 1$ = 0 s, $\tau 2$ = 64 yr = 2.02109 s)

needs are covered by drilled wells providing warm and brackish water, which is of inadequate quality both for human consumption and/or agriculture. The use of such geothermal water as a source for the production of freshwater using its heat as an energy source for its desalination can be an efficient method of freshwater production which avoids environmental impacts.

While the desalination of saline waters has now been accepted as a potential alternative method of providing freshwater supplies, the energy demands of existing desalination technologies for water production continue to pose challenges in their application [5].

In several areas wells deep enough or located in areas with positive temperature anomalies can provide waters with temperatures high enough for desalination. This kind of geothermal system exists in many parts of the World, including Poland. The Podhale district heating system located in the southern part of Poland is currently the largest geothermal heating plant in Poland and one of the biggest in Europe. As seen in our previous research [7,8], effective management of geothermal waters discharged from the heat exchanger (about 56–58 °C) can include treatment to obtain high quality drinking water. The combined process might be of interest in water scarce regions worldwide. However, when water treatment systems are located far from the ocean or the sea, disposal of the concentrate obtained from the treatment process is a challenge and an economic concern; injecting into deep geological systems could be the preferred solution [9].