

Special Issue: New Trends in Enhanced, Hybrid and Integrated Geothermal Systems

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1. Introduction

The most important challenge for the global energy sector is to rapidly transform the entire system to one less dependent on fossil fuels and so reduce the harmful effects on the climate. In sharp contrast, the global energy demand, mainly being met by fossil fuel resources, is continuing to grow, primarily in response to population and economic growth [1]. Therefore, finding, developing, and utilizing effective, economical, and practical solutions to the ongoing and emerging challenges is essential. Meeting the global energy demand and simultaneously minimizing the negative consequences of climate change and the threat of global warming requires a transition to energy systems largely based on non-carbon renewable energy sources (e.g., solar, wind, geothermal, and hydro) [2]. Geothermal energy installations—shallow, deep, or a combination of both—provide sustainable and environmentally friendly energy. Exploiting this source consists of extracting and/or storing the Earth's thermal energy for use in meeting electricity and heating/cooling needs for a variety of applications, including to heat and cool dwellings and greenhouses, provide warm and/or cold water for agricultural products in greenhouses, and even to de-ice roadways and parking areas [3].

The main goal of this Special Issue has been to address the existing knowledge gaps and help advance the deployment of geothermal energy projects worldwide. Of the twelve articles submitted, eight were accepted for publication after the peer-review process, an acceptance rate of ~67 percent. The published articles, briefly described in the following section, cover a range of topics and applications central to geothermal energy.

2. Summary of Published Articles

In the first article, Akbari Kordlar et al. [4] proposed a novel and adjustable tri-generation system—driven by geothermal heat sources—to meet the heating and cooling demands of a particular district network in Germany based on ambient air temperature. Their tri-generation system integrates a modified absorption refrigeration cycle and a Kalina cycle, utilizing a mixture of ammonia–water as the working fluid for the entire system. To examine the impact of various operational parameters on the system's performance before optimization, they conducted a sensitive analysis in off-design conditions, taking into account mass, energy, and exergy balances, and also off-design model equations for each component as a control volume. Their simulation results reveal that the proposed tri-generation system can meet the required heating and cooling demands. The authors also optimized the proposed system based on two criteria: the maximum exergy efficiency (the first scenario) and minimum total exergy destruction rate (the second scenario). The optimization results indicate that (1) a maximum mean exergy efficiency in the first scenario is obtained as 44.67 percent at the expense of a 14.52 percent increase in the total exergy destruction rate compared to the second scenario; (2) a minimum mean total exergy

destruction rate in the second scenario is calculated as 2980 kW at the expense of an 8.32 percent reduction in the exergy efficiency in the first scenario; and (3) taking into account both the exergy efficiency and total exergy destruction rate in off-design conditions, the best enhancement via the optimization process is achieved on a typical cloudy workday in winter, with 53.21 percent exergy efficiency and a 2570 kW total exergy destruction rate. Comparing the optimization results for both scenarios shows that the system's performance is more improved in the second scenario.

Kim et al. [5] experimentally analyzed a smart geothermal heating and cooling heat pump system consisting of an open loop—meaning the use of underground water from an aquifer—by means of a standing column well (SCW) and cross-mixing balancing well heat exchangers. To do so, they modified the present operational technique of two adjacent SCW geothermal heat exchangers, each with a single well. The authors employed this technology in order to improve the coefficient of performance (COP) of the geothermal system, basically through preventing underground water discharge and sustaining a constant temperature in the underground heat exchanger. The two balancing wells were utilized in the cross-mixing methods to restrain the bleed water discharge. According to the authors' findings, the mean amounts of COP measured from the balanced well cross-heat exchange system were, respectively, 3.76 and 3.27 throughout the cooling and heating operations. In other words, they achieved COP enhancements of 23 and 12 percent, respectively, during the cooling and heating operations compared to the present SCW method of the heat exchange system. Moreover, while utilizing a balancing well cross-mixed heat exchange system, the initial underground temperature was kept constant, with only a small standard deviation of 0.08–0.12 °C over 3–5 days of continuous operation, meaning that a relatively stable heat source supply is possible.

Maleki Zanjani et al. [6] numerically investigated the effect of utilizing fins on both the interior and exterior U-tube surfaces of a ground heat exchanger (GHE) under cooling mode, plus axial speed and temperature contours due to the tube curvature for an internally finned U-tube at different speeds. They then compared the results with results obtained from a finless U-tube GHE under the same physical conditions. The authors also simulated both dynamic and static behaviour of simple and finned (both internally and externally) U-tube GHEs to determine the impacts of longitudinal fins on the thermal performance of borehole heat exchangers (BHEs) and the heat transfer rate between circulating fluid and soil around the tubes. The dynamic simulations contained short timescale and frequency response tests. In fact, the authors' goal in performing the dynamic and static simulations was to find the best thermal efficiency. The simulation results illustrate that interior fins enhance the rate of heat transfer more effectively, so that the maximum fluid temperature variation was ~2.9 percent in the tube with exterior fins, and ~11.3 percent in the tube with interior fins, instead of the simple tube. Additionally, increasing the inlet fluid speed can make the differences more substantial in temperature profiles and changes, so changing the inlet fluid speed in the range of 0.02–0.06 m/s enhances the fluid temperature variation in the internally finned U-tube by 5–11.3 percent, in comparison with the finless U-tube. In contrast, the fluid temperature variation is only increased by 0.5–2.9 percent when the external fins are utilized. As for the dynamic behaviour, the priority of the interior fins is also apparent. Generally, the research performed by Maleki Zanjani et al. [6] confirms that the use of fins positively influences fluid temperature variations within the tube as well as the rate of heat transfer between the fluid and the borehole wall. The use of fins, especially interior fins, also enhances the thermal efficiency of a ground source heat pump system and reduces the length of the tube required and the initial expenses of the system.

Huang et al. [7] evaluated and reported on a location for a planned geothermal project, called the Alberta No. 1 project, which would produce power and heat (for direct use) at a commercial scale. The project is situated within the Municipal District of Greenview, south of the city of Grande Prairie, Alberta, Canada, and the evaluations demonstrate that there is a high likelihood of fluids up to 120 °C at depths of approximately 4000 m. According to the assessments conducted by the Alberta No. 1 project team, the target formations for

this planned geothermal project consist of dolomitized carbonate units of the Devonian age from the Beaverhill Lake Group to the top of the Precambrian Basement. Additionally, Permeable Devonian-aged sandstone units such as the Granite Wash Formation are also targets. The authors' findings suggest that elevations at the top of the Beaverhill Lake Group range from 3104 m to 4094 m, and temperatures at the top of the formation range from 87 °C to 123 °C in the project area.

Several potential challenges regarding the performance of sedimentary geothermal well-doublet systems, including heat conductivity, geochemical, and geomechanical conditions and issues, have been comprehensively examined and discussed by Mahbaz et al. [8]. These challenges may occur in the processes inside the reservoir itself, such as channelling, mineral precipitation and flow, and in the access and energy systems such as wells, heat exchangers, pumps, and surface tubing insulation. Some of their findings include that: (1) Chemical reactions can result in changes of flow-path, plus alterations of the rate of heat exchange between rock and water, and, consequently, changes in the reservoir's porosity-permeability and heat capacity; (2) Corrosion and scaling damage in the well-doublet systems diminish their performance and also influence their life-span; (3) Factors such as energy discharge rate and strategy, rate of injection, temperature and heat management, and well spacing contribute substantially to the heat recovery and life-span of a geothermal well-doublet system; (4) The injection of geothermal fluid such as water, carbon dioxide, and air into a well-doublet system can induce stress variations at a scale that will increase the likelihood of fault/fracture reactivation and induced seismicity. Therefore, realizing the magnitude of these events and their recurrence in time is important; (5) Factors including channeling, short-circuiting, leaking, heterogeneity, and permeability impairment can influence project viability, so they must be carefully evaluated during site assessment. Recognizing and understanding these challenges and issues will assist designers/engineers in better designing, implementing, and operating sedimentary geothermal well-doublet systems, leading to improved performance and increased efficiency of these types of systems, in addition to lessening their associated expenses and risks.

Gao et al. [9], by means of a hydro-thermal coupling model, numerically examined the impact of fluid flow direction on the heat transfer performance and specifications in a granite single fracture and validated the accuracy of the numerical modeling results experimentally. Their findings indicate a consistently robust relationship between the distribution of the local heat transfer coefficient and the fracture profile, independent of the axis. An alteration in the direction of the fluid flow is likely to change the amount of the heat transfer coefficient, but does not influence the distribution specifications along the flow pathway. An increase in the rate of injection fluid flow has an enhanced influence. Although the heat transfer capacity in the fractured rises with the rate of fluid flow, a sharp reduction in the rate of heat extraction and the total heat transfer coefficient is also seen. In addition, the model with the smooth fracture surface in the flow direction reveals a greater heat transfer capacity in comparison with that of the fracture model with differing roughness. This finding is attributed to the existence of fluid deflection and dominant channels.

The study conducted by Gizzi et al. [10] deals with the reuse of abandoned or disused deep hydrocarbon wells in Italian oilfields to extract the associated geothermal resources. The authors utilized existing information on Italian oil and gas wells and on-field temperatures to employ a simplified closed-loop coaxial wellbore heat exchanger (WBHE) model at three hydrocarbon wells positioned in different Italian oilfields, namely, the Villafortuna–Trecate, Val d'Agri-Tempe Rossa, and Gela fields. The goal was, in fact, to appropriately examine the heat transfer mechanisms of the three, focusing on the fact that the potential to extract thermal energy can alter based on the geological and sedimentary context. The results demonstrate considerable difference between the potential quantities of thermal energy to be extracted from the three wells studied. Taking into account the maximum extracted working fluid temperature of 100 °C and hypothesizing a cascading exploitation mode of the heat accumulated, it was only possible for the Villafortuna 1

WBHE to consider a multi-purpose and comprehensive use of the resource, based on the use of existing infrastructure, available technologies, and current knowledge.

In the last article, Ćuković Ignjatović et al. [11] evaluated an approach for the cascade utilization of geothermal energy potential for space heating and cooling and balneological treatments in the most south-eastern region of the Pannonian basin, in Central Europe. For this purpose, they selected two specific sites with various geothermal resources (meaning different temperatures and chemical compositions) and located within different urban contexts—one in a natural environment called Ljuba and the other inside a small settlement called Banatsko Veliko Selo—situated in the province of Vojvodina, northern Serbia. At the Ljuba site, a geothermal spring with a temperature of 20.5 °C was characterized to employ a geothermal heat pump (GHP) for the production of heat, whereas at the Banatsko Veliko Selo site, a geothermal well with a temperature of 54 °C was appropriate for direct use. The authors calculated the available thermal power from the geothermal resource according to geothermal conditions for both sites, ranging from 300 kW (GHP) to 950 kW (direct use), along with the cascade method of utilization. At the same time, they proposed a development concept with an architectural design, matched with energy availability based on the modularity concept, to enable sustainable energy-efficient development of wellness and spa/medical facilities that can be supported by local authorities. The resulting energy heating demands for different scenarios were 16–105 kW, which can fully be supplied by geothermal energy.

3. Future Research Need

Although submission to this Special Issue is now closed, the need for further in-depth research and development related to geothermal technologies and systems (stand-alone or hybrid) remains. Due to the specifications of geothermal energy, such as a local, potentially constant, robust, generally available, resilient, almost greenhouse gas-free, and long-lived energy source, it is anticipated that this renewable and sustainable source of energy will play a more prominent role in the future global energy supply mix.

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Abbreviations

BHEs	Borehole Heat Exchangers
COP	Coefficient of Performance
GHP	Geothermal Heat Pump
GHE	Ground Heat Exchanger
SCW	Standing Column Well
WBHE	Wellbore Heat Exchanger

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