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Editorial

Frontier Research of Engineering: Geothermal Energy Utilization and Groundwater Heat Pump Systems

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Geothermal energy is a near-inexhaustible and multi-purpose resource capable of satisfying global energy demand while lowering the reliance on fossil fuels for primary energy [1–3]. Geothermal energy, which is produced by thermal energy and stored within the Earth, can produce electricity and meet the heating and cooling needs of buildings globally [4,5]. This versatility is of great importance given the geopolitical dependency on fossil fuels and the large greenhouse gas emissions they produce. Geothermal energy benefits from the internal energy of the Earth that is mainly related to the temperature gradient (geothermal gradient) from the core (~6000 °C) to the surface (air temperature). In the depths that are accessible by drilling with the current technology (~10,000 m), the average geothermal gradient is 25–32 $^{\circ}C \cdot km^{-1}$ [6]. In these circumstances, there are various technological obstacles that geothermal energy must overcome for its successful application [7,8]. The Special Issue, entitled 'Frontier Research of Engineering: Geothermal Energy Utilization and Groundwater Heat Pump Systems' will address some of the most challenging technological issues in the field of geothermal energy.

Geothermal systems are composed of three elements: a heat source, a reservoir and a fluid. The heat source can range from a magmatic intrusion at >500 °C to the Earth's surface temperature in low-temperature systems. The reservoir is defined by a volume of permeable rocks from which the circulating fluids (most of the time, water) extract heat. Even though the heat source is always natural, hydraulic fracturing can increase reservoir permeability and injection wells can supply fluids [9]. High- (>150 °C) and intermediate-enthalpy (90–150 °C) geothermal resources are primarily used for electricity generation, while low-enthalpy geothermal resources (<90 °C) are suitable for a wide range of applications.

Electricity is largely produced in conventional steam turbines and binary plants [10]. Conventional steam turbines require fluids at temperatures >150 °C and can operate with either atmospheric or condensing exhausts. For geothermal fluids that are in the range of 85–170 °C, binary plants use a secondary working fluid—often an organic fluid with a low boiling point and high vapor pressure at low temperatures. To reach reservoirs with temperatures that allow electricity production, wells typically need to be several kilometers deep. This poses a technological barrier and raises the cost and complexity of these geothermal energy installations. Deep well drilling technology is usually only cost-effective for oil wells, and geothermal energy is frequently a second use of abandoned oil wells [11]. High-enthalpy reservoirs can only be used at shallower depths in regions with high geothermal gradients, such as volcanic zones.

Pipelines that transport geothermal fluids and, frequently, re-injection wells, are required for geothermal energy exploitation in addition to the production wells and a utilization facility [12]. Pipelines can transport geothermal fluids over long distances, but must ensure proper thermal insulation and prevent corrosion and leaks. Recent research is helping to better understand how fluid properties are affected by the geometry of leaks in pipe walls [13]. The exploitation of high-enthalpy geothermal energy may increase the likelihood of land subsidence and earthquakes [14]. The development of technology to improve seismic monitoring, reduce stress and aftershocks, and prevent earthquakes of a larger magnitude is key to minimizing risk [15,16]. The use of CO_2 as a working fluid in deep mines and enhanced geothermal systems (EGSs), which combine carbon storage and geothermal extraction, has also drawn significant interest in recent studies [17].

The internal energy in low-enthalpy geothermal systems is insufficient to produce electricity. Low-enthalpy geothermal systems, however, are accessible with less expensive and sophisticated technology because they are located closer to the surface [18]. As a result, they constitute a thermal reservoir that is exceptionally valuable for both heating and cooling. Direct geothermal use refers to the internal energy transfer between geological materials and surface thermodynamic systems without converting it into work [19]. Since ancient times, people have used geothermal energy directly (for example, using caves to prevent seasonal temperature fluctuations), but it was not until the invention of mechanical drilling and heat pump technology in the nineteenth century that this technology could be widely used. Heat pumps work by recovering heat stored naturally in ground or groundwater, and can be used either for heating or cooling. Some heat pumps allow dual functioning, i.e., heating operation in winter and cooling operation in summer. Groundwater heat pump (GWHP) systems are increasingly used for the cooling and heating of buildings due to their relatively lower cost, easier installation and higher performance than ground heat pumps. In groundwater heat pump systems, the water passes through heat pumps to extract (heating) or release (cooling) heat before being discharged into the aquifer. The efficiency of this process is determined by the coefficient of performance (COP), which compares the amount of usable heating or cooling provided to the amount of work (energy) required. GWHPs operated for heating return the water to the aquifer at a lower temperature, while GWHPs operated for cooling return the water at a higher temperature. In both situations, the natural temperature of the aquifer is modified, which is essential for assessing environmental impact and performance losses [20–23]. Fiber optic technology has emerged as a suitable technology for monitoring groundwater temperature, as well as for estimating hydraulic and thermal aquifer properties, which are of great importance for the performance of geothermal exploitation [24,25]. Hydraulic and thermal parameter estimation also benefits from the continuous development of advanced inverse modelling tools [26].

In this context, it is essential to better understand the hydro–thermo–chemical processes involved in the use of geothermal energy and to investigate new technologies and methods that contribute to facilitating or enhancing the exploration, exploitation and performance of geothermal energy systems, as well as to reducing and monitoring their potential environmental impacts.

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