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Editorial: Progress in Exploration, Development and Utilization of Geothermal Energy

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Editorial on the Research Topic

Progress in Exploration, Development and Utilization of Geothermal Energy

1 INTRODUCTION

This Research Topic includes 27 papers, grouped under the Research Topic "*Progress in Exploration, Development and Utilization of Geothermal Energy.*" This editorial highlights each of the papers, which relate to two major aspects and six sub-aspects, including geothermal energy exploration including geothermal geology, geothermal system conceptual model and geothermal resource assessment, and geothermal development and utilization including shallow geothermal energy, hydrothermal energy, and enhanced geothermal systems (EGSs).

2 GEOTHERMAL ENERGY EXPLORATION

2.1 Geothermal Fields

Geothermal fields include a geological description of the present geothermal fields and paleo geothermal fields. Thermal history is a significant constraint in accurately restoring the characteristics of the paleo geothermal fields (Jiang et al., 2021). Gao and Li studied the thermal history of the Fuyang sag for the first time based on their geophysical exploration and drilling results.

The present geothermal fields represented in this Research Topic mainly include terrestrial heat flow and thermal structure research, rock thermal conductivity and heat production rate researches, and remote sensing data in geothermal applications (Zuo et al., 2020).

2.1.1 Terrestrial Heat Flow and Thermal Structure Research

Based on the surface heat flow and rock thermal properties, Zhu et al. evaluated the temperature distribution characteristics and discussed the primary influencing factors on the geothermal state of the Sichuan Basin. Xu et al. calculated the geothermal gradient and terrestrial heat flow in the Xi'an Depression of the Weihe Basin and indicated a high thermal background in the area. Lithospheric thermal structure refers to the ratio of the heat flow between the crust and the mantle in a region and its fabric relationship (Zuo et al., 2020). The distribution of heat flow of crust and mantle affects the distribution of deep temperature and the activity of crust and upper mantle. Liu et al. selected the Yanheying Basin, a typical intermountain basin located in the eastern foothills of the Yanshan Mountain, to undertake a comprehensive analysis of heat flow and lithospheric thermal structure, to have a better understanding of the geothermal background and resource utilization potential of the area.

2.1.2 Rock Thermal Conductivity and Heat Production Rate Research

Rock thermal properties include the thermal conductivity and radioactive heat production of rocks. Zeng et al. proposed a novel fractal model with variation pore diameter relating to effective thermal conductivity and the microstructural parameters and fluid properties. This model improved the accuracy of predicting effective thermal conductivity. Cui et al. calculated the radioactive heat production of sedimentary layers and igneous rocks using the logging curve and analyzed the influence of igneous rock distribution, residual heat, and its thermal increment on the crust.

2.1.3 Remote Sensing Data in Geothermal Applications

The inversion of surface temperature is particularly important for the present geothermal field. Dong et al. systematically reviewed the characteristics of surface temperature retrieval methods. Based on Landsat 8 remote sensing data, the differences among these three algorithms (Radiative Transfer Equation, Mono-Window Algorithm, and Split window Algorithm) were researched by adopting them to detect the surface temperature in Kangding County, Sichuan Province, China.

2.2 Geothermal System Conceptual Model

The geothermal system mainly includes five elements, namely a heat source, a fluid source, a flow path, a thermal reservoir, and cap rock.

The heat sources of sedimentary basins mainly come from two parts, one is the heat generated by the decay of radioactive elements in the crust and the other is the heat flow in the deep mantle. Wang et al. reviewed the exploration process of deep geothermal resources in the North Jiangsu Basin and outlined that the geothermal genesis mechanism has been influenced by mantle-source heat and the upper crustal-scale heat control, which was mainly caused by thermal refraction. Chemical composition and the isotopes of fluids are often used to trace fluid source and path. Xing et al. used the Piper trigram and Na-K-Mg software to explore the genesis of underground hot water. They revealed the genesis of the Gaoyang geothermal field based on the water chemistry and isotopic in the geothermal fluid. Wang et al. performed a comprehensive investigation using multiple chemical and isotopic tracers (δ^2H, δ^{18}O, ^{87}Sr/^{86}Sr, δ^{13}C, and ^{14}C) to reconcile the anomalies and examine both the recharging water source and the circulation dynamics of these geothermal systems.

Zhang et al. systematically collected indicators including ^{14}C dating, ^{18}O, and ^{2}H to identify the dominant flow path of regional carbonate geothermal water. They indicated that the geothermal water in areas with young ^{14}C age, a high value of D, and weak ^{18}O drift phenomenon had good flow conditions. Tian et al. reported new data on chemical compositions and He–Ne–C isotopes for gas samples from representative hot springs and wells in the Guangdong and Fujian provinces to identify the origin of hydrothermal volatiles and provided insight into geothermal tectonic affinities. They revealed that the NE-trending faults were heat-control tectonic structures and that their intersections with the NW-trending faults provided expedite channels for geothermal fluid rising to the surface. Baoqing et al. observed that the microtremor survey method is often adopted for geothermal exploration in urban areas. Using this method, the Rayleigh wave dispersion curve was extracted using spatial autocorrelation based on the vertical component signal at the observation station. A genetic algorithm was then used to invert the dispersion curve of one survey point to obtain strata parameters such as layer thickness, S-wave velocity, and density. This approach provided critical parameters for the cap layers and reservoirs for geothermal exploration. On the cause and overall evaluation of the geothermal system, Zheng et al. studied the geological conditions of the deep granite reservoir and discussed the genesis of the deep granite geothermal system based on rock geochemistry and zircon U-Pb chronology. They proved that there is a huge amount of deep granite geothermal resources in the southeastern coastal area in China. Li et al. systematically analyzed the nature and forming mechanisms of the Xifeng low-temperature geothermal field using element geochemical (ions, rare Earth elements) and stable isotopic (D, O) composition. They assigned the geothermal field as a faults-controlling and deeply circulating meteoric water of low-temperature category.

2.3 Geothermal Resources Assessment

Geothermal resource assessment involves calculating and evaluating verified, proven, controlled, and inferred geothermal resources, which are based on a comprehensive analysis of the exploration results of geothermal resources and using reasonable methods. Yuan et al. analyzed the mechanism and prediction of geothermal resources controlled by neotectonics in mountainous areas and established a conceptual model of geothermal resources in southeastern Zhangjiakou City, China. This conceptual model is verified by the geothermal fields already discovered in the study area and has been proven to be reasonable. A potential drilling site was also predicted and showed success. Huang et al. proposed a revised volumetric approach for evaluating the deep geothermal potential in an active oil field by integrating a 3D geological model into a hydrothermal (HT)-coupled numerical model. Integrating the 3D geological modeling and HT numerical model into the geothermal resource assessment improved its accuracy and helped to identify the distribution map of the available geothermal resources, which indicated optimal locations for further development and utilization of the geothermal resources.

3 GEOTHERMAL DEVELOPMENT AND UTILIZATION

3.1 Shallow Geothermal Energy

Shallow geothermal energy refers to the low-temperature geothermal energy stored in water, soil, and rocks at depths of 200 m between the surface and the underground. They contribute most to the utilization of geothermal energy with help from heat pump technology. Two papers in this issue shed light on advances in this area. Zhu et al. simulated the heat transferring process of the groundwater heat pump system in terms of a single well. They found the major reasons leading to the cold accumulation and then optimized single-well technology to improve the coefficient of performance (COP). They also introduced the concept of borehole thermal energy storage (BTES), which is paper's other main theme. Meng et al. discussed the thermal impact of the long-term utilization of BTES. The environmental impact of the interaction with hydrocarbon contaminants was also investigated using OpenGeoSys software. They concluded that the change of subsurface temperature will lead to the alteration of hydrocarbon contaminants. For example, they found that over 70% of the trichloroethylene mass was removed from a discontinuous contaminant plume after 5 years of operation of a small BTES installation in their modeled scenarios.

3.2 Hydrothermal Energy

Hydrothermal energy is geothermal energy utilized in terms of extracting groundwater fluids generally without help from a heat pump (Kong et al., 2014). Six papers in this Research Topic address this issue. To extract the geothermal fluid, the primary approach is to perform the borehole. Zhang and Li examined the affecting factors on the thermal insulation cement of a geothermal borehole, as they show, porosity, with Skeleton ingredients, curing temperature, and test temperature being vital factors.

Three papers focus on the optimization of hydrothermal energy. Yuan et al. carried out a numerical simulation based on the monitoring data in a small geothermal reservoir. They found an optimized strategy for a multi-well layout to prevent fast water level drawdown through reinjection. They also checked the factors of openhole length, production rate, and reinjection water temperature on the heat performance. Such a strategy is of course useful for geothermal energy utilization of hydrothermal energy. Sun et al. considered the sustainable utilization of hydrothermal energy in complex geological layers with faults. Both 2D and 3D numerical models were employed to establish that groundwater reinjection strategies should be carried out in advance. They emphasized the detailed geological parameters of the fracture zone, which should be examined further for better utilization of hydrothermal energy. These results can be compared with those of Kong et al. (2017a), who developed a model to couple numerical simulation and economic analysis. In the follow-up work included here, Fan et al. developed a model to estimate the recovery ratio, which is useful for assessing geothermal energy during the production process at a geothermal field.

Different from the three geological papers mentioned above, Zhao et al. focused on the power generation method to utilize hydrothermal energy. Two systems, including binary flashing cycle (BFC) and organic Rankine cycle (ORC), are compared in terms of thermodynamic and economic performance. They described the effects on the performance of several indicators including thermal efficiency, exergy efficiency, net power output per ton of geothermal water, heat exchanger area, and heat recovery efficiency. Their results showed that the BFC can realize the full utilization of low-grade energy.

One paper in this Research Topic utilized geothermal energy without extracting geothermal fluid. Such technology is called the deep borehole heat exchanger (DBHE). Following the heat exchange model developed by Kong et al. (2017b), Cai et al. performed a comprehensive economic analysis of DBHE in 15 heating seasons. They found the minimum COP is 4.74 in their study area of the Weihe Basin in Northwest China. They also undertook an optimal analysis and concluded that a depth of 2,600 m has the lowest Levelized cost of total heating amount (LCOH) for the Weihe Basin, which could support geothermal energy in this region.

3.3 EGS

The EGS is a major way of utilizing hot dry rock geothermal energy, although it is also used for hydrothermal energy (Kong et al., 2021). Two papers in this issue are included in this Research Topic.

The key technology for developing an EGS reservoir is hydraulic fracturing. Xu et al. studied the characteristics of damage zone porosity for stimulation in a sandstone reservoir. A simulation experiment was carried out to locate the damage zone. Meanwhile, the effects of high temperature and pressure were also examined in this paper. Another important aspect of extracting geothermal energy using EGS is the working fluid. Lei compared CO_2 and H_2O using the data in the Songliao Basin, Northeast China. Considering the temperature drop limitation at the downhole of the production well, he concluded that the heat extraction performance was better using H_2O than that using CO_2 as the working fluid. However, there were also disadvantages to using CO_2, because the CO_2 based EGS had a low-power consumption for maintaining fluid circulation.

AUTHOR CONTRIBUTIONS

YZ, SJ, and MY summarized the geothermal energy exploration; YK, HS, and HZ summarized the geothermal development and utilization.

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