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Editorial

Advanced Progress of the Geo-Energy Technology in China

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1. Introduction

Geological energy has a long history in China. As early as 500 BC, China began to use coal as fuel. In the middle of the 19th century, China began to develop oil resources. After the foundation of new China, with the discovery of the Daqing oilfield, China's oil industry entered an era of great development. During the 21st century, with the development of drilling technology, the development of unconventional energy (e.g., shale gas and shale oil) has entered a new era. In recent years, the development of flammable ice has ushered in a wave of clean energy. With the carbon reduction plan proposed by the Chinese government, clean geo-energy is set for unparalleled development in the near future.

China's geo-energy development technology previously lagged behind that of major developed countries for a long time, but after years of development, it has become world-leading in some fields. Therefore, for this Special Issue, we specially selected papers from a variety of authors in order to summarize China's advanced geo-energy exploitation technology and development trends and provide some new directions for thinking about geo-energy development in China and the world at large. This collection seeks to contribute to such topics through enhanced scientific and multidisciplinary knowledge and contains papers on innovative technical developments, reviews, case studies, and analytical and assessment papers from different disciplines that are relevant to the topic of geo-energy.

After the announcement of the creation of this Special Issue, more than twenty well-known scholars submitted their research work for publication. After strict quality screening and peer-review procedures, fourteen high-level papers were selected and have been published in *Energies*.

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Citation: Zhu, C.; Yang, S.; Pu, Y.; Sun, L.; Wang, M.; Du, K. Advanced Progress of the Geo-Energy Technology in China. *Energies* **2023**, *16*, 6812. https://doi.org/10.3390/en16196812

Received: 13 September 2023
Accepted: 15 September 2023
Published: 26 September 2023

2. Special Issue Content

Huang et al. (2022) [1] divided the pre-peak crack strain evolution curve of rock into three stages based on the triaxial compression test results of granite and the definition of crack strain. According to the nonlinear variation characteristics of crack strain in the stage of rock crack stable propagation, rock deformation is expressed as the sum of matrix strain and crack strain. Subsequently, the exponential constitutive relationship of rock crack stable propagation was deduced. The axial crack strains of the rock sample and its longitudinal section were equal. Thus, the longitudinal symmetry plane of the rock sample was abstracted as a model containing sliding crack structure in an elastic body, and the evolution equation of crack geometric parameters in the process of stable crack propagation was obtained. Compared with experimental data, their results show that the crack strain-based rock crack stable propagation model can adequately describe the evolution law of crack strain and wing crack length. In addition, the wing crack propagates easily when the elastic body with small width contains an initial crack with a large length and an axial dip angle of 45° under compressive load. This study provides a new avenue for analyzing the stable propagation characteristics and laws of rock cracks under compressive load.

In an in situ conversion project, it is difficult to directly obtain cores through drilling for kerogen maturity testing, and in-depth research on investigating the reaction process of subsurface pyrolysis based on the maturity of oil products has not been carried out. Zeng et al. (2022) [2] carried out simulation experiments and a geochemical analysis based on the oil shale of the Nenjiang Formation in the Songliao Basin and the pyrolysis oil samples produced by an in situ conversion project. Additionally, this study aimed to clarify the evolution characteristics of maturity parameters such as effective biomarker compounds during the evolution of oil shale pyrolysis hydrocarbon products and align them with the kerogen maturity in the Nenjiang formation. A response relationship with the oil shale pyrolysis process was established, laying a theoretical foundation for the efficient, economical, and stable operation of oil shale in in situ conversion projects.

Jiao et al. (2022) [3] examined coal samples inside and outside the outburst holes of the Sanjia coal mine to reveal the distribution characteristics of functional groups and the difference in microcrystalline structure parameters between outburst coal and primary coal. The functional groups and microcrystalline structure parameters of outburst coal and primary coal in the Sanjia coal mine were studied via infrared spectroscopy, X-ray diffraction (XRD) experiments, and the peak-splitting fitting method. Their results showed that the substitution mode of the benzene ring in an aromatic structure was mainly benzene ring tri-substituted, with the percentage of primary coal being 32.71% and the percentage of outburst coal being 31.6%. The primary coal contained more functional groups from which hydrogen bonds can easily be formed, meaning that gas is not easily adsorbed by coal. The aromatic hydrogen rate (fHa) of the outburst coal was 0.271. The aromatic carbon rate (fC) was 0.986; the aromaticity I1 was 0.477. I2 was 0.373, and the length of the aliphatic branched chain (ACH2/ACH3) was 0.850.

Liu et al. (2022) [4] integrated core, logging, and 3D seismic data to conduct a comprehensive seismic–geological study on the sedimentary evolution characteristics and peat accumulation regularity of the Shanxi Formation in the Xinjing mining area of the Qinshui Basin. Firstly, the high-resolution sequence interface was identified, and the isochronous stratigraphic framework of the coal-bearing series was constructed. Then, the temporal and spatial evolution of sedimentary filling and sedimentary facies was dynamically analyzed using waveform clustering, phase rotation, stratal slice, and frequency–division amplitude fusion methods. Their results show that the Shanxi Formation in the study area can be divided into one third-order sequence and two fourth-order sequences. It developed a river-dominated deltaic system, mainly with delta plain deposits, and underwent a constructive–abandoned–constructive development stage. The locally distributed No. 6 coal seam was formed in a backswamp environment, with distribution constrained by the distributary channels. The delta was abandoned at the later stage of the SS1 sequence, and the peat accumulation rate was balanced with the growth rate of the accommodation, forming a widely distributed No. 3 thick coal seam. During the formation of the SS2 sequence, the No. 3 coal seam was locally thinned via the epigenetic erosion of the river, and the thin coal belt (caused by erosion) was controlled by the location of the distributary channels and their extension direction.

Xia et al. (2022) [5] employed a coupled lattice Boltzmann method and discrete element method (LBM-DEM) to study the sand production process of porous media. A simulation of the sand production process was conducted, and the force chain network evolvement was analyzed. The absolute and relative permeability changes that take place before and after the sand production process were studied. The effect of injection flow rate, cementation strength, and confining pressure are investigated. During the simulation, strong force chain rupture and force chain reorganization were identified. The mean shortest path distance of the porous media reduced gradually after an initial sharp decrease, while the mean degree and clustering coefficients increased in the same way. Furthermore, the degree of preferential wettability for water increased after the sand production process. Moreover, the existence of a critical flow rate below which porous media can reach a steady state was noted. This study's results also show that porous media is more stable under higher confining pressure due to the higher friction resistance between particles preventing sand production.

Duan et al. (2022a) [6] considered the interaction between pipeline fluid motion and water hammer wave propagation based on the essence of water hammer, with the pressure, velocity, density, and overflow areas set as variables. A new set of water hammer calculation equations was deduced and solved numerically. The effects of different valve closing times, flow rates, and gas contents on pressure distribution and the water hammer effect were studied. It was found that with the increase in valve closing time, the maximum fluctuating pressure at the pipe end decreased, and the time of peak value also lagged behind. When the valve closing time increased from 5 s to 25 s, the difference in water hammer pressure was 0.72 MPa, and the difference in velocity fluctuation amplitude was 0.076 m/s. These findings confirm the following: the greater the flow, the greater the pressure change at the pipe end; the faster the speed change, the more obvious the water hammer effect. High-volume flows were greatly disturbed by instantaneous obstacles such as valve closing. With an increase in time, the pressure fluctuation gradually attenuated along the pipe length. The place with the greatest water hammer effect was near the valve. Under the coupling effect of time and tube length, the shorter the time and the shorter the tube length, the more obvious the pressure fluctuation.

Duan et al. (2022b) [7] used a single tubing to simulate and analyze the modal changes of the tubing under dry mode and wet mode, respectively. In their study, the effects of a fluid–solid coupling effect, inlet pressure, and ambient temperature on the modal of the tubing are discussed. After considering the fluid–structure interaction effect, the natural frequency of tubing decreases, but the displacement is slightly larger. The greater the pressure in the tubing, the greater the equivalent stress on the tubing body; thus, the natural frequency is lower. Furthermore, after considering the fluid–solid coupling effect, the pressure in the tubing is the true pulsating pressure of the fluid. The pre-stress applied to the tubing wall changes with time, and the pressures at different parts are different. At this time, the tubing is changed at different frequencies. Vibration is prone to occur; in other words, the natural frequency is smaller than the dry mode. The higher the temperature, the lower the rigidity of the tubing and the faster the strength attenuation; therefore, the natural frequency is lower, and the tubing is more prone to vibration. Both the stress intensity and the elastic strain increase with increasing temperature, so the displacement of the tubing also increases.

Yan et al. (2021) [8] used ocean bottom seismic data to perform first-arrival tomography, which showed two obvious phenomena: (1) a low-velocity (3.3 to 4 km/s) zone with a size of 20×3 km^2 (centering at ~4.5 km depth) and (2) an underlying high-velocity (5.5 to 6.3 km/s) zone of comparable size at ~7 km depth. MCS profiles showed highly fragmented Cenozoic sequences that covered a wide chaotic reflection zone within the Mesozoic strata below hill H110. The low-velocity zone corresponded to the chaotic reflection zone and can be interpreted as a derivative of the highly fractured and fluid-rich Mesozoic layers. Samples dredged from H110 composed of illite-bearing authigenic carbonate nodules and rich, deep-water organisms were indicative of deep-source hydrocarbon seepage. Therefore, H110 could be inferred as a mud volcano. The high-velocity zone was interpreted to be a result of magma intrusion, considering that young magmatism was found to be enhanced compared to the southern CSD. Furthermore, the origin of H110 was speculated to be thermodynamically driven, i.e., magma from the depths intrudes into the thick Mesozoic strata and promotes petroleum generation, thereby driving mud volcanism.

Mud volcanism at H110 and the occurrence of a low-velocity zone below it likely indicates the existence of a Mesozoic hydrocarbon reservoir that favors petroleum exploration.

Xie et al. (2021) [9] proposed the use of extreme gradient boosting (XGBoost) trees to estimate the incremental oil production of conformance control with N2-foam and gel for cyclic steam-stimulated horizontal wells. A database consisting of 1000 data points was constructed using numerical simulations based on the geological and fluid properties of the heavy oil reservoir in the Chunfeng Oilfield; this dataset was then used to train and validate the XGBoost model. The results of this study show that the XGBoost model is capable of estimating incremental oil production with relatively high accuracy. The mean absolute errors (MAEs), mean relative errors (MRE), and correlation coefficients were 12.37/80.89 t, 0.09%/0.059%, and 0.99/0.98 for the training/validation sets, respectively. The validity of the prediction model was further confirmed via comparison with numerical simulations for six real production wells in the Chunfeng Oilfield. The permutation indices (PI) based on the XGBoost model indicate that the net/gross ratio (NTG) and the cumulative injection of the plugging agent exert the most significant effects on the enhanced oil production.

Elastic wave propagation in partially saturated reservoir rocks induces fluid flow in multi-scale pore spaces, leading to wave anelasticity (velocity dispersion and attenuation). The propagation characteristics cannot be described by a single scale flow-induced dissipation mechanism. To overcome this problem, Wu et al. (2021) [10] combined the White patchy saturation theory and the squirt flow model to obtain a new anelasticity theory for wave propagation. This study examined a small sandstone-rich area in Qingyang, Ordos Basin, and involved performing ultrasonic measurements at partial saturation and different confining pressures; the properties of the rocks were obtained at full gas saturation. A comparison between experimental data and the theoretical results demonstrated fairly good agreement, indicating the efficacy of the new theory.

Yang et al. (2021) [11] carried out multi-step loading and unloading creep tests with permeability measurements at confining stresses of 30 MPa on pre-cracked sandstone specimens that had been thermally heat-treated to 250, 500, 750, and 1000 °C. Their observations indicate that a critical threshold temperature of 500 °C is required to generate thermally induced cracks, with subsequent strength reduction occurring at 750 °C. A comparison of creep histories and visco-elastic and visco-plastic strains highlighted the existence of a strain jump at a certain deviatoric stress level—where the intervening rock bridge between the twin starter-cracks is eliminated. As the deviatoric stress level increases, the visco-plastic strains make up an important composition of total creep strain, especially for specimens pre-treated at higher temperatures, and the development of the visco-plastic strain leads to the time-dependent failure of the rock. The thermal pre-treatment produced thermal cracks in the rocks, with their closure resulting in increased instantaneous elastic strains and instantaneous plastic strains. With an increase in stress ratio, the steady-state creep rates increased slowly before the failure stress ratio but increased suddenly over the final stress ratio to failure. However, pre-treatment temperature had no clear and apparent influence on the steady creep strain rates. Rock specimens subject to higher pre-treatment temperatures exhibited higher permeabilities. The pre-existing cracks close under compression, with a coplanar shear crack propagating from the starter cracks and ultimately linking these formerly separate cracks.

Based on leak-off data, pore fluid pressure, and rock mechanics parameters, Jia et al. (2021) [12] used the Fault Analysis Seal Technology (FAST) method to analyze the hydraulic fracture risk of mudstones in central depression. The results of this study show that the blocks in the diapir zone have been subjected to hydraulic fracturing in the Huangliu cap rocks throughout geological history and that the blocks in the slope zone, which is a small distance from the diapir zone, have a lower overall risk of hydraulic fracture than that of the diapir zone. In terms of geological history, the cap rocks in the slope zone remained closed for a longer time than that in the diapir zone, and the cap rocks in the slope zone experienced a decrease in hydraulic fracture risk with increasing distance from the diapirs. These results are consistent with the enrichment of natural gas, which accumulated in both the Yinggehai Formation and Huangliu Formation of the diapir zone but only accumulated in the Huangliu Formations of the slope zone. The most reasonable explanation for the difference in the gas reservoir distribution is that the diapirs promote the development of hydraulic fractures; (1) diapirism transfers deep overpressure to shallow layers, and (2) the small fault and fractures induced by diapir activities weakened the cap rock and reduced the critical condition for the natural hydraulic fractures.

Under asymmetric load, pump house lining is easily damaged, resulting in the need for overall chamber repair. To address this problem, taking the pump house in Wanfu Coal Mine under construction in China as an engineering example, Huang et al. (2021) [13] analyzed the asymmetric failure of pump house lining caused by construction disturbance; established a mechanical model for lining and quantitative evaluation indexes, such as bending moment change rate, bending moment balance rate, displacement change rate and displacement balance rate; studied the influence mechanism of asymmetrical coefficient, section size, and lining thickness on the mechanical behavior of lining; and proposed control measures for the deep large section of the chamber with the aim of "strengthening asymmetric support, reducing section size and improving lining strength". The field monitoring results show that the asymmetric deformation of the pump house was effectively controlled, and the maximum displacement was only 7.3 mm, ensuring the long-term stability of the chamber.

Si et al. (2021) [14] proposed the indexes of airflow disorder, including excavation roadway length, outburst pressure, air door pressure difference, and auxiliary fan air quantity. Using the orthogonal table of L9 (34) and a numerical simulation method, the characteristics of airflow reversal were studied, and the outburst airflow reversal degree should the ventilation facility fail was calculated. Furthermore, on the basis of fuzzy comprehensive optimization theory, a comprehensive evaluation model for the airflow disorder was established. The results of this study show that excavation roadway length is the most important factor affecting the stability of the ventilation system, followed by the outburst pressure, air door pressure difference, and auxiliary fan air quantity. The influence of a gas outburst accident on the return air system is greater than that on the inlet air system, and a larger air velocity has a greater impact on the ventilation system, especially the air inlet part. Moreover, the airflow reversal degree of the ventilation system increases with an increase in outburst pressure or decreases with the length of the excavation roadway. This paper provides a basis for the prevention of gas outburst accidents.

3. Closing Remarks

The papers presented in this Special Issue cover important aspects of the latest advances in advanced geo-energy technology in China. Despite advanced geo-energy technology in China being an extensive topic, this small contribution to the literature could help stimulate current and ongoing research and improve its progress. Therefore, we believe that the papers presented here will have practical importance for future development with respect to advanced geo-energy technology in China. Finally, we wish to thank the authors that contributed to this Special Issue.

Author Contributions: All authors are considered to have contributed equally to the article. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the opening fund of State Key Laboratory of Mining Response and Disaster Prevention and Control in Deep Coal Mines (Grant No. SKLMRDPC21KF04) and the opening fund of State Key Laboratory of Coal Mine Disaster Dynamics and Control (2011DA105827-FW202209).

Acknowledgments: We would like to acknowledge the authors who contributed to this Special Issue.

Conflicts of Interest: The authors declare no conflict of interest.

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