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Editorial

Mine Water Safety and Environment: Chinese Experience

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1. Introduction

Coal occupies a central position in the global energy sector. As a major source of fossil fuels, coal has a profound impact on the global economy and energy security [1,2]. There are abundant coal reserves and many coal-forming periods in the world, and the occurrence of deep coal resources varies greatly across different regions [3]. The hydrogeological conditions of mines are complex and of different types [4,5]. In order to ensure normal mining conditions, it is necessary to take measures such as dewatering and reducing pressure and discharging mine waste water to reduce the influence of groundwater continuously gushing from roadway and mining face on mine production [6]. The natural drainage of coal bearing aquifers and the loss of Quaternary aquifers caused by artificial drainage and water-conducting cracks formed by mining seriously damage groundwater and surface water resources. Therefore, coal mining must discharge a large amount of mine water and then produce a series of water quantity and quality problems. The lifespan of a coal mine (i.e., mining exploration, construction, production, and closure) is challenged by mine water safety, groundwater pollution, mine water resource utilization, and ecological environment protection [7–9]. Although many scholars have been rapidly advancing the field by adopting new ideas and concepts, the safety of mining conditions [10–12] and the groundwater environment in the mining area [13–15] have been greatly improved, and the technology, processes, and materials of mine water prevention and treatment have been greatly developed, but there are still some problems. These include the development of new methods and models for the management of floor and roof mine water inrush hazards, the sampling and detection of pollutants in the coal mine area, high-efficiency and low-cost mine water treatment, unconventional mine water resources utilization, groundwater protection, geological storage of mine water, etc.

Prevention and control of mine water inrush hazard is the first issue that needs to be solved to ensure the safety of coal mining. Although there have been many research reports on this issue, due to the complex hydrogeological conditions of mines, further research is still needed on water inrush warning, grouting sealing of water inrush aquifers, and flow field disturbances caused by coal mining. Water-preserved coal mining is the process of selecting reasonable mining methods and processes to prevent damage to the water bearing structure of the aquifer caused by mining activities. Although it may be damaged to some extent, causing partial loss of water flow, the water level of the aquifer can still be restored after a certain period of time. The amount of loss should ensure that the minimum water level does not affect the growth of surface plants and that the water quality is not polluted. Water-preserved coal mining mainly include inhibiting the development of water conducting fracture zones through filling mining and other technologies, reconstructing and grouting the aquiclude, and the co-mining of coal and water resources. To protect water resources, the treatment and utilization of mine water

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and mine water reinjection and geological storage are receiving increasing attention. In addition, after the closure of the mine, drainage stops, the groundwater level rises, and abandoned shafts, tunnels, and goaf areas are submerged. Adequate water–rock (coal) interaction occurs in these areas, making abandoned mines a potential source of pollution and causing pollution to regional groundwater through various means for a considerable period of time [16–18]. Therefore, elucidating the formation and evolution mechanism of mine water quality, constructing multi-field coupling numerical model of mine water pollution, and then carrying out prediction and prevention of groundwater pollution in coal mine areas have become important means of theoretical and technical support to ensure the green and sustainable development of the coal industry. The formation and evolution process of mine water quality is mainly controlled by multiple fields, namely, the hydrodynamic field, hydrochemical field, and microbial field. At present, scholars, both domestically and internationally, have conducted extensive research on the hydrodynamic and hydrochemical fields in coal mining areas. However, there are still few reports on the effects of multi-field coupling under the influence of microorganisms on the formation and evolution of water quality.

We have initiated this Special Issue with an edition entitled "Mine Water Safety and Environment". It contains ten articles and one review, which we briefly describe in the next section, ranging from the prevention and control of mine water inrush hazards, the treatment and utilization of mine water, the modeling of groundwater in the mining area, and the prevention and control of mine water pollution to the geoevolution and biogeochemical process of mine water quality, aiming to promote the green and sustainable development of the coal industry.

2. An Overview of Published Articles

Mine water inrush, gas, and other issues are major safety hazards that currently constrain coal mine production. Identifying the mechanism of water inrush, risk assessment, and rock damage patterns and reducing gas concentration are essential. Six papers in this Special Issue cover topics relevant to this subject.

Wang et al. proposed a roof water inrush risk assessment method (GIS-MCDA) based on the probability-based Monte Carlo analytic hierarchy process (MAHP) combined with the ordered weighted average (OWA) operator for the risk assessment of coal mine roof water inrush. This method uses the OWA operator to quantify the five risk response attitudes of decision makers and incorporates the risk attitudes of decision makers into the evaluation process. This makes the roof water inrush risk assessment results more objective and comprehensive, reducing or avoiding the risks brought to decision-making due to changes in people's subjective tendencies. In addition, this method is applied in the mine production process, demonstrating its ability to improve the objectivity and comprehensiveness of risk assessment.

Zheng and Pang studied the damage law and preventive measures of the base under the action of water and rock. Their article analyzed the coupling of karst water and basement rock based on rock mechanics and fracture mechanics and pointed out, through mechanical tests, that the water–rock coupling seriously destroyed the stability of the coal seam floor. A three-dimensional numerical model was established using FLAC3D software to simulate the mining conditions of the working face under different water pressures. By analyzing the stress changes of the base, the changes in water pressure, and the damage in the plastic zone, the law of the damage effect of different water pressures on the base was found.

Shi et al. used a gravity-loaded rock seepage test device to conduct seepage tests on coal samples with different fracture lengths and inclinations under different stress conditions. A three-dimensional seepage model with a larger fracture length (1–30 m) was established using COMSOL numerical simulation software. Combined with multiple regression analysis, the sensitivity of fracture seepage to a variety of related influencing factors was explored. The nonlinear relationship between the permeability of small and large fractures and the fracture length was pointed out, and the critical fracture length scale was identified. This contributes new insights into the seepage patterns of fractures of different sizes and the transport laws of fracture water.

Li et al. took the 14,030 panel of the Zhaogu No. 2 Coal Mine as their research object and studied the formation mechanism of roof water inrush and sand collapse from the thin bedrock field in the deep-buried mining area. Through physical experiments, theoretical analysis, and field investigation, it was revealed that the height and limit span of the water-conducting fracture zone experienced four stages: initial stage, slow growth stage, sudden growth stage, and stable growth stage. A coupling model of roof movement and phreatic flow in a deep-buried thin bedrock chute was constructed, and a deep-buried thin bedrock roof structure stability control technology based on "settlement arch-cantilever beam" was proposed.

Yang et al. proposed an improved water source identification model for the identification of water inrush sources during coal mining. The model combines algorithms such as data mining, classification models, and reinforcement learning. The proposed PCA-GA-ET method combines principal component analysis (PCA) for dimensionality reduction, genetic algorithm (GA) optimization of extreme tree (ET) classifier parameters, and the ET algorithm for water source classification. Compared with the commonly used SVM and MLP models, the PCA-GA-ET model has a better fitting effect on the data, which proves the reliability of the PCA-GA-ET model. This method has shown high efficiency, accuracy, and robustness in identifying water sources under the condition of a large number of sample databases and is applicable to complex hydrogeological conditions, even in small datasets.

Sun et al. conducted research on microseismic monitoring systems and hydraulic fracturing technology in coal mine gas control. First, the radio tunnel perspective method and infrared differential absorption method are used to detect the geological structure and gas concentration in the mining area; then, hydraulic fracturing related parameters are determined; and finally, hydraulic fracturing technology is implemented. Using microseismic monitoring technology to monitor the cracks formed during hydraulic fracturing construction and evaluate the fracturing effect. This is an effective method for effectively controlling coal mine gas concentration and improving coal mine safety production level.

Water has two sides; it can carry boats or capsize them. Compared to mine water disasters, there should be mine water conservancy. So, in the field of mineral development, the focus should be on mine water hazards while also considering mine water conservancy. Therefore, the duality of mine water can be completely unified, for example, through the comprehensive utilization of mine water, water conservation and coal mining, mine water recharge, green mining, mine water pollution and prevention, underground reservoirs, and coal–water co-mining. Four papers in this Special issue explore the relevant topics mentioned above:

Zhang et al. adopted a numerical simulation method and used FLAC3D software to analyze the formation process, water storage capacity, and central reservoir location of the underground water reservoir in Zhangshuanglou Coal Mine. The formation process of the underground water reservoir in the coal mine was simulated, and its water storage capacity as an underground water reservoir in the coal mining area was calculated. This shows that the construction of underground water reservoirs in coal mines is a key step for mining enterprises to achieve green production, protect groundwater resources, and promote water recycling.

Zhang et al. took the equivalent permeability coefficient (EPC) of the "soil–rock" composite impermeable layer and the response mechanism of shallow groundwater in multi-mine mining as the starting point to evaluate, quantitatively, the impact of mining activities on the shallow groundwater system at the mine field scale. Using mathematical statistics, numerical simulation, and theoretical analysis methods, a six-level evaluation method for improving the response mechanism of shallow groundwater in multi-mine mining was proposed. The method was then used to evaluate the distribution characteristics of the water resource carrying capacity (WRCC) of the shallow groundwater system in the Yushen mining area. The article emphasizes that the traditional idea of development first and then protection or pollution treatment should be broken, and a strategic layout of reasonable planning before mining and prudent regulation during mining is proposed.

Li et al. investigated the occurrence of polycyclic aromatic hydrocarbons (PAHs) in the soil and groundwater of a typical coking plant. The forward matrix factorization model (PMF) was used to identify the sources of PAHs in the study area. The health risks of PAHs in the area were evaluated. This provides a basis for further analysis of the migration and transformation process of PAHs, which helps to take targeted pollution prevention and control measures and subsequent risk management. It is believed that this kind of research can provide some useful references for pollution control, secondary utilization, and future site remediation of similar coking sites.

Xu et al. found that the microbial ecology and geochemical processes in specific areas of deep mining environments have not been fully explored and understood, which limits the problem of mine water pollution and prevention. The study was conducted in the Xinjulong Coal Mine, a typical coalfield in North China, and it analyzed the response of microbial communities and sediment geochemical characteristics to coal mining disturbances. Sediment samples were collected from five different functional areas, including rock tunnels, coal tunnels, goafs, pools, and surface water. The relationship between microbial communities and water chemical processes was explored. The decrease in the concentration of characteristic pollutants SO_4^{2-} in the goaf reflects that it has a self-purification ability as the closure time increases. This provides a scientific basis for the bioremediation of mine water pollution.

In this Special Issue, the topic of comprehensive groundwater prevention and control engineering in coal mines is discussed. There is no doubt that curtain grouting technology is important throughout the entire lifespan of a coal mine. One paper is presented on this subject:

Yuan et al. reviewed the application and prospects of curtain grouting technology in China's mine water safety management. The authors summarized the construction conditions, theoretical design and effects, drilling structure, and grouting materials of curtain grouting technology, and put forward the main problems of mine curtain grouting technology. Moreover, they analyzed the development prospects of these aspects. As a comprehensive groundwater prevention and control project in the whole lifespan of a mine, curtain grouting technology plays an important role in ensuring the coordinated development of resource development and regional ecological protection and is the inevitable choice for achieving sustainable development and green mine construction.

3. Conclusions

This Special Issue published multidisciplinary scholarly works focusing on obtaining an in-depth understanding of the scientific principles and mechanisms, including critical technology, challenges, and ideas, for mine water hazard and pollution prevention, water-preserved coal mining, the treatment and utilization of mine water, the geo-evolution and biogeochemical process of mine water quality, and the modeling of groundwater in mining areas.

Grounded on the previous gaps reported above, there are several potential directions of study that could be implemented to elucidate the mechanism of mine water safety and environmental pollution. This Special Issue, "Mine Water Safety and Environment", identifies the following research directions:

(1) Mine water reinjection and geological storage: The reinjection of mine water is based on the premises of not deteriorating the water quality of the recharge layer and not affecting the safety of coal mining. Different from conventional groundwater recharge, mine water recharge has significant coal mine area characteristics. Affected by a complex hydrogeological structure, not only is the difference in mine water in the coal mine area obvious, the requirements and technology of coal mine safety mining are also different. The purpose of mine water reinjection and geological storage is to

realize the coordinated mining of coal and water resources, the green mining of coal, and the water conservation mining of coal. Its main purpose is to reduce the surface displacement of mine water, reduce the cost of mine water treatment, and protect the groundwater resources in the study area in line with the high-TDS mine water "blocking, reducing, protecting" overall treatment idea. Therefore, more and more attention has been paid to mine water reinjection in recent years.

(2) Hydrodynamic–chemical–microbial combined action in mine water quality: The formation and evolution process of mine water quality is very complex and controlled by multiple fields, namely, the hydrodynamic field, the hydrochemical field, and the microbial field. At present, there are few reports in the literature that can depict the special hydrodynamic field of a coal mine goaf while considering the coupling effect of multiple fields. This is mainly limited by the particularity of the groundwater dynamic field in coal mine areas and the complexity of multi-field effects, which leads to difficulties in the application of relevant basic theories and technologies. The mechanism of multi-field coupling and the mutual influence between parameters under complex geological prototypes are among the many challenges faced by multi-field coupling.

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