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# The Research Status and Prospect of Guided Fracturing in the Field of Gas Prevention and Control

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## Abstract

**In recent years, the country strongly promotes the management goal of "zero over-limit" of gas and "zero outburst" of coal seam. It is urgent to develop systematic, efficient and reliable pressure relief gas extraction technology to realize comprehensive utilization of gas energy and avoid the occurrence of gas disasters. With the mining of coal mines from shallow to deep, traditional gas extraction techniques based on the development of shallow coal seams are becoming more and more "unsuitable". Guided fracturing overcomes the disadvantages of conventional hydraulic fracturing technology of single fracture formed in the direction of maximum principal stress and "blank zone" of anti-reflection on both sides, and greatly improves the anti-reflection efficiency of coal seam. Currently, there are four main means to induce the expansion direction of hydraulic fractures, namely radial injection fracturing, control hole guiding, non-uniform pore pressure guiding and slotted compound hydraulic fracturing, can realize directional permeability enhancement of coal seam. Among them, the slotted compound hydraulic fracturing technology has the advantages of easy implementation and strong operability and controllability, and has a broad development prospect. Most of the current experimental studies on slotted compound hydraulic fracturing have focused on the direction of slit deviation angle, horizontal stress difference coefficient. In order to better develop and utilize this technology, we can start with the effective action range and applicable conditions of the slit length and spacing on the pressure crack in the soft seam with difficult seam formation and stable overburden roof; for improving the effective extension efficiency of fractured fractures in coal-rock complex formation, the formation mechanism of three-dimensional fracture network system of guided staged fracturing was studied and the evolution law of stress field in the process was explored, thus promote the wide application of hydraulic fracturing technology in coal mine disaster prevention.**

## Keywords

**Guided Fracturing; Gas Prevention; Coal Seam Permeability Enhancement; Crack Extension.**

## 1. Introduction

As a major coal producing and consuming country, China produced 4.13 billion tons of raw coal in 2021, an increase of 5.7% from the previous year, and the share of coal consumption in primary energy consumption is still high (Figure 1-3), although it is decreasing year by year [1]. As coal mines are mined from shallow to deep, the increase in effective stress further inhibits the coal seam gas seepage Klinkenberg effect, again reducing the coal seam permeability [2], and the risk of coal mine

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disasters is further highlighted, with 91 coal mine accidents, 6 coal and gas herniation accidents, and 24 fatalities occurring in 2021 alone. Throughout the years, coal mine gas accidents (Figure 4) have profoundly revealed that there is a long way to go to upgrade research on the mechanism of coal and gas protrusion and anti-surge technology in deep mining [3-4]. In order to effectively curb the risk of coal and gas protrusion and achieve the balance of "extraction and mining" in the protruding coal seam, hydraulic fracturing technology uses the loading of external load to communicate the channel of gas desorption flow inside the coal seam, so as to improve the amount of gas extraction and achieve the purpose of gas control.

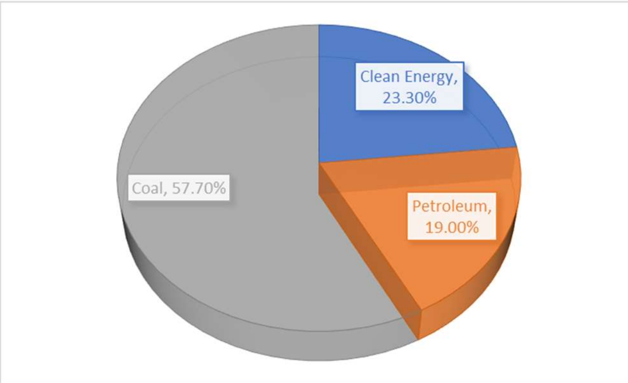


**Fig. 1** Structure of China's energy consumption in 2019

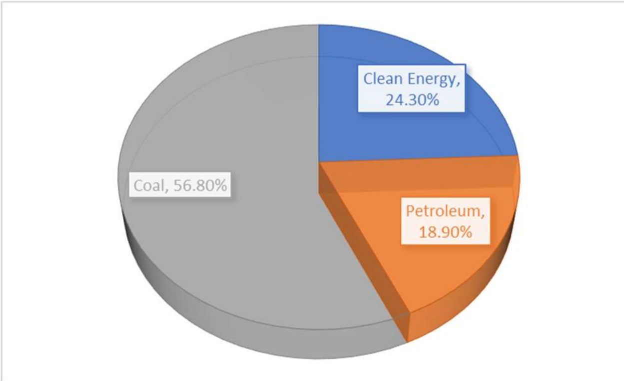


**Fig. 2** Structure of China's energy consumption in 2020

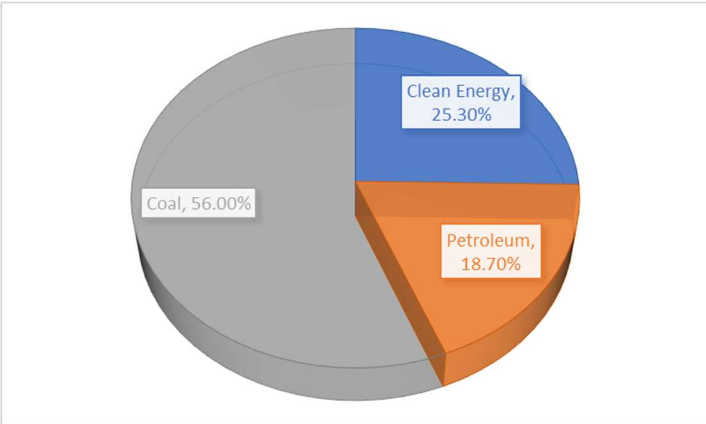


**Fig. 3** Structure of China's energy consumption in 2021

However, during the transformation process of conventional hydraulic fracturing technology, it was found that the fractures formed under the action of high flow rate and high pressure are easily restricted by the original ground stress, which manifests as a single fracture pattern and limited transformation range [5]. In view of this, some scholars proposed to use hydraulic fracturing combined with other penetration enhancement techniques to induce the expansion of hydraulic fractures, and then achieve the purpose of directional penetration enhancement in coal seams. At this stage, the research on guided fracturing is still to be improved, especially the mechanism of inducing fracture directional expansion and the scope of action are still unclear. Based on this, this paper reviews the current research status of guided fracturing in the field of gas prevention and control, and outlooks the future research directions.

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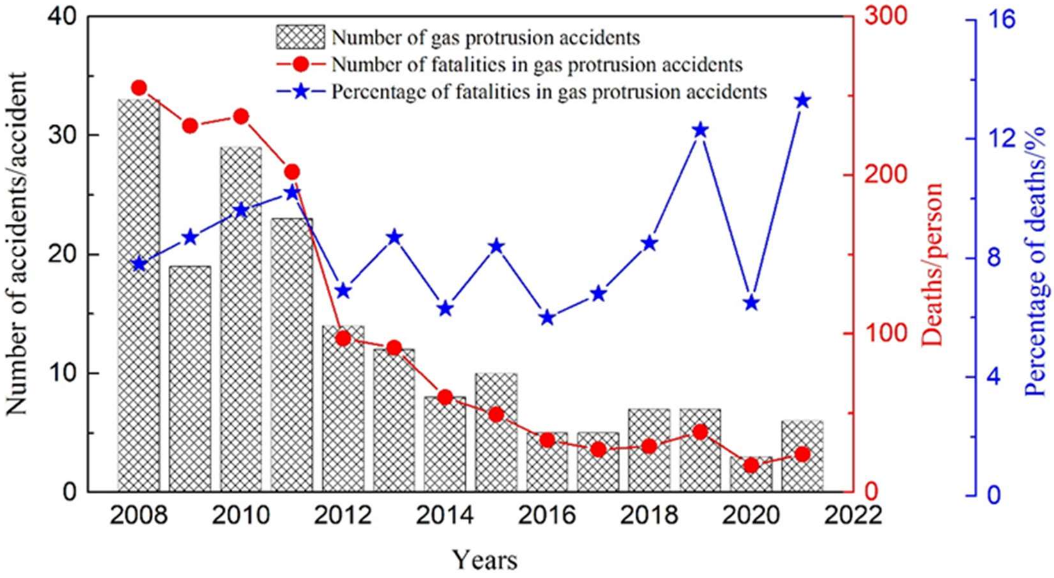


**Fig. 4** Statistics of coal mine gas outburst accidents from 2008 to 2021

## 2. Current status of research on the mechanism of coal and gas protrusion

Coal and gas protrusion (Figure 5-6) is a mixture of coal dust and high-pressure gas airflow ejected from the coal seam under the synergistic effect of ground stress and gas pressure, which expands and desorbs to the stable airflow of the roadway after completing compression, forming a protrusion shock wave [6-7], and the study of its occurrence mechanism is an important part of gas protrusion control.

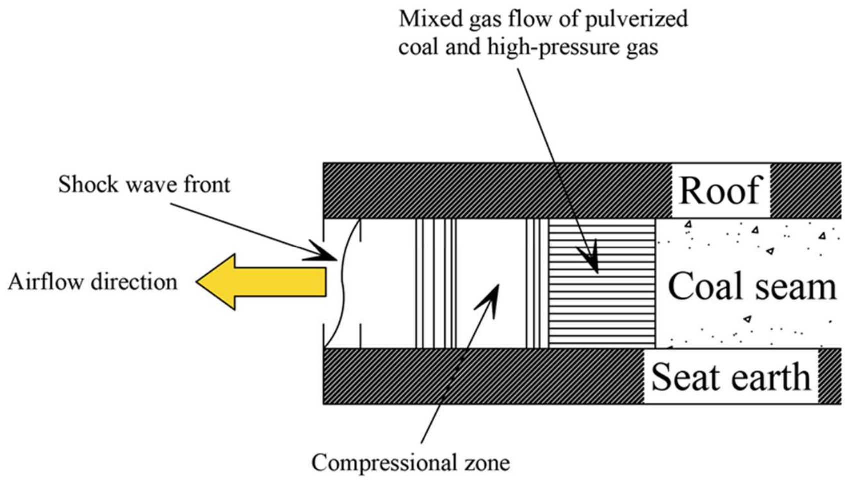


**Fig. 5** Diagram of coal and gas outburst process

After a lot of research, scholars have mainly attributed coal and gas protrusion factors to four types of views: gas dominant role hypothesis, ground pressure dominant role hypothesis, chemical nature role hypothesis, and integrated role hypothesis [8]. However, these hypotheses can only explain some of the protrusion phenomena and are not universally applicable. Based on this, He [9] proposed the "rheological hypothesis" by analyzing the mechanical properties of gas-bearing coals, which suggested that the coal body undergoes rheological behavior when the external load exceeds the yield load limit of the coal; Jiang [10] suggested that during the protrusion process, the coal body is first damaged by the ground stress, and then the desorption of gas inside the coal body promotes the expansion of cracks and the formation of a spherical coal shell. Finally, the gas again caused the destabilization of the coal shell and threw it into the mining space, i.e., the "spherical shell destabilization hypothesis", which better explained the shape and formation process of the protrusion hole; Yuan [11] incorporated the factors of ground stress, tectonic conditions, coal body strength and gas pressure, and established a real three-dimensional coal and gas protrusion quantitative physical simulation system. Wang [12] used FVM to numerically simulate the effect of gas desorption on the propagation characteristics of protruding shock waves and gas flow; Wei [13] carried out a study on the evolution law of stress field after unloading of gas-bearing coal through a fluid-solid coupling model, and analyzed the role of ground stress in the process of coal and gas protrusion.

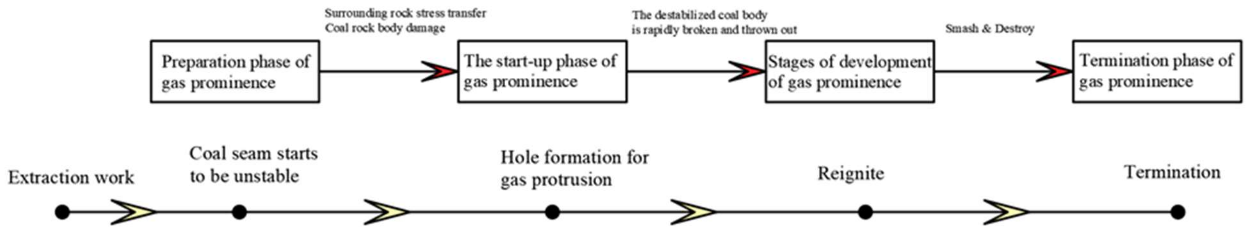


**Fig. 6** Phase division of coal and gas outburst based on mechanical action process

In summary, many scholars have interpreted the coal gas fugacity and desorption characteristics through experimental studies and constructed a large number of models, which have achieved different reactions to explain the coal and gas protrusion phenomenon. However, the systematic theory of prominence destabilization criterion and prominence phenomenon in deep coal seam with complex fugacity conditions still needs further research.

## 3. Current Status of Research on Fracture Initiation and Expansion Mechanism of Hydraulic Fractures

### 3.1 Study on Fracture Initiation Mechanism of Hydraulic Fracture.

M.K Hubert et al [14-15] proposed the theory of tensile damage initiation considering that fracturing would concentrate the stress in the hole wall, and by analyzing the circumferential tensile stress in the well wall, the critical condition of fracture initiation was derived, that is, the circumferential tensile stress was greater than the tensile strength of the hole wall; Dunlap I.R et al [16-17] studied the interaction between the fractured hole and the ground stress, and concluded that the fracture extended and extended along the maximum principal stress direction. The results laid the foundation for the subsequent study of hydraulic fracturing; Lu [18] incorporated the factors of ground stress and coal seam storage state, constructed the judgment criterion of hydraulic fracture initiation in coal seam, and clarified the influence of coal seam azimuth and inclination angle on fracture initiation; Zhao [19] used the criterion of maximum axial tensile stress as the criterion of hydraulic fracture initiation, and deduced the fracture initiation angle and critical hydraulic pressure.

Numerous scholars have studied numerous crack initiation pressure calculation models, and the more used crack initiation pressure calculation models and applicable conditions [20-26] are shown in Table 1.

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**Table 1.** Crack initiation pressure calculation model and applicable conditions

| No. | Computational Models | Applicable conditions |
|---|---|---|
| 1 | $p_b = \sigma_t + (3\sigma_h - \sigma_H)$ | Impermeable non-initial pore p-ressure rocks |
| 2 | $p_b = \sigma_t + (3\sigma_h - \sigma_H) - p_0$ | Impermeable rocks with initial pore pressure |
| 3 | $p_b = (3\sigma_h - \sigma_H) - p_0$ | Second liqui-d injection cycle |
| 4 | $p_b = \dfrac{\sigma_t + (3\sigma_h - \sigma_H) - \alpha\gamma p_0}{2 - \alpha\gamma}$ | Suitable for r-ocks that are per-meable and have i-nitial void pressu-re that based on Biot-poroelasticit-y theory |
| 5 | $p_b = \sigma_t + (3\sigma_h - \sigma_H) - \beta p_0$ | Suitable for i-mpermeable rock-s with low porosi-ty; compressibilit-y of the rock is c-onsidered based o-n the principle of effective stress of the Taisha base |
| 6 | $p_b = \dfrac{\sigma_t + (3\sigma_h - \sigma_H) - \alpha\gamma p_0}{1 + \beta - \alpha\gamma}$ | Suitable for permeable rocks with low porosity; based on the mod-ified effective str-ess principle |
| 7 | $p_b = \cos\varphi + (1 + \sin\varphi)\dfrac{\sigma_t}{2} + (1 + \sin\varphi)\sigma_h$ | Rupture whe-n pore wall stress reaches shear stre-ngth |
| 8 | $p_b = \dfrac{1}{h_0(L, r_w) + h_\alpha(L, r_w)}\left[\dfrac{K_{IC}}{\sqrt{r_w}} + \sigma_H f(L, r_w) + \sigma_h g(L, r_w)\right]$ | Assume caus-ed by the unstabl-e expansion of cr-acks |

The calculation model in the table shows that the fracture initiation pressure of fracture depends on the ground stress and rock strength if the relative compressibility of rock and pore pressure variation are not considered; when the compressibility of rock and pore pressure variation are considered, the fracture initiation mechanism of fracture is more complicated. The existing research has transitioned from single lithology to multi-combination lithology and from single reservoir to multi-combination reservoir, but there are primary joints inside the coal seam, and the non-homogeneity characteristics within and between the layers are obvious, and a large number of structural weak surfaces and other influencing factors are developed, and there is a lack of systematic research on the fracture expansion pattern and fracture initiation mechanism before and after fracturing of multi-combination coal-rock complex.

### 3.2 Hydraulic Fracture Expansion Law Study

Numerous scholars at home and abroad have conducted a lot of research on the expansion of hydraulic fractures with the goal of transforming to obtain high connectivity fractures and complex seam networks in coal seams. Zhao [27], in studying the expansion law of hydraulic fractures and natural fractures during shale fracturing, found that when hydraulic fractures deflect toward natural fractures, they turn simultaneously at both ends of the structural surface in order to form a complex fracture network structure; Hou [28] proposed to adopt "Fracture communication area (SRA)", that is, the sum of the areas of hydraulic fractures communicated with natural fractures and bedding planes, as the index to evaluate the expansion scale of fracture network; Li [29] concluded that the angle between the main stress direction and natural fractures, the number and length of fractures and the extension length of the main fractures are negatively correlated on the basis of the influence of the angle between the natural fractures and the main stress in the coal seam.

In summary, the research on the influence of coal seam angle and ground stress factors on hydraulic fracture modification is more systematic, and it is generally agreed that the macro mechanical characteristics of coal seams cause the hydraulic fractures to be short and wide with a single form,

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which cannot play an effective role in improving the permeability of coal seams, but there are still gaps in the research on the influence of the original pore fracture characteristics of coal seams on the control role of hydraulic fractures and the effect of increasing permeability, and there is a lack of quantitative characterization of the effect of hydraulic fracturing on increasing permeability There is a lack of quantitative characterization methods for the effect of hydraulic fracturing on increasing permeability.

## 4. Status of Research on Hydraulic Fracture-guided Extension Technology

Considering that the fractures formed by hydraulic fracturing technology are susceptible to the original ground stress, the problem of limited extent of penetration increase and "blank zone" of penetration increase on both sides of the main fracture (Figure 7) will occur in the actual downhole transformation. According to the research of scholars, there are four main methods to induce the expansion direction of hydraulic fractures: radial injection fracturing, control hole guiding, non-uniform pore pressure guiding and slit composite fracturing.

Jiang [30] proposed the combination of radial shot hole technique and hydraulic fracturing to induce the expansion of hydraulic fractures, and demonstrated the feasibility of radial shot hole fracturing technique to form biplane steering fractures in the formation through physical simulation experiments; Fu [31] carried out a radial shot hole true triaxial fracturing experiment for radial shot hole length and angle, and compared the model under various lateral stress ratios through the model establishment of The results showed that the fracture initiation from the laminar surface will produce a horizontal main fracture and several vertical fractures to build a fracture network structure, and the increase of the shot hole length will lead to the decrease of the initiation pressure and the increase of the horizontal guidance range; Lu [32-33] studied the effect of the rock's own inhomogeneity on the internal stress field and the seepage field, and concluded that the non-uniform pore pressure field can guide the fracture expansion. Li [34] used the method of directional control hole guidance based on the stress concentration phenomenon after fracturing the coal seam, and studied the action mechanism of control holes, and determined that the placement of holes 3-4 m away from the fracture holes could play an effective role in assisting the free surface and promoting the fracture orientation and accelerated expansion.

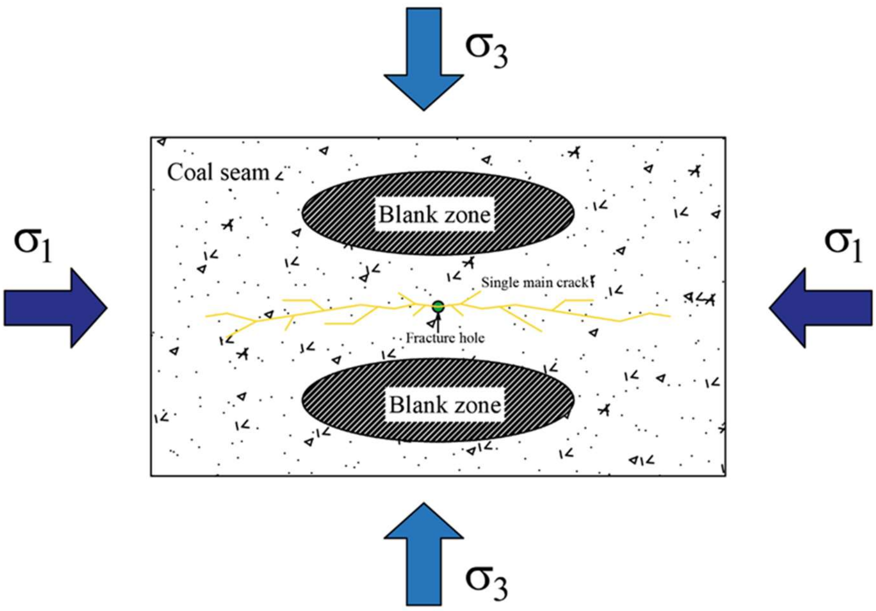


**Fig. 7** Penetration enhancement "blank zone" in conventional hydraulic fracturing

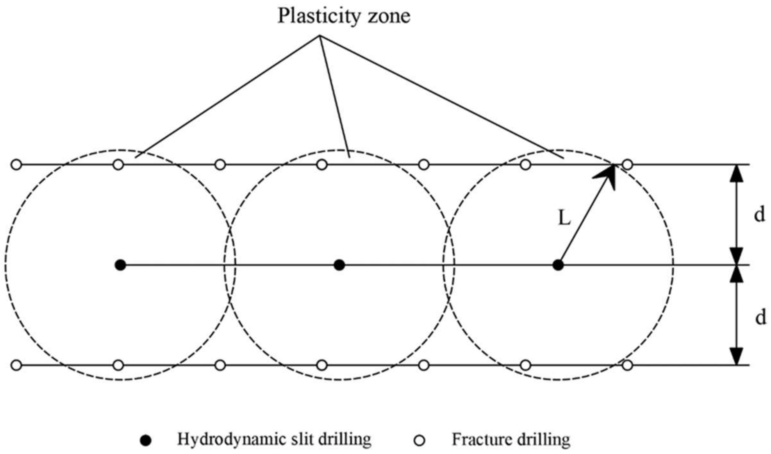


**Fig. 8** Synergistic arrangement of hydraulic cuttings and hydraulic fracturing boreholes

In cut-guided fracturing (Fig. 8), Deng et al [35] took prefabricated fractures in the specimen with the help of real triaxial fracturing experiments and finite element analysis to derive the influence law of cut length, angle and injection rate on the initiation and expansion of guided fracture; Lu [36] established a guided fracture induction model based on the action law of pore pressure gradient and cut-guided fracture, and used RFPA and FLAC3D carried out the study of the pore pressure gradient field and the law of action of hydraulic slit on the internal coal rock, and clarified the control conditions of slit-guided extension through the evolution of slit-guided fracture paths; Xu [37] proposed a drilling arrangement process of combined slit-pressure penetration enhancement technology for low-permeability coal seams, and through the study of the range of damage zone, plastic zone, elastic zone and original rock stress zone around the drilling, determined the best location for hydraulic initiation of fracture is within the weak surface of the plastic zone formed by the cuttings, and a better application was achieved in engineering practical measurements.

Through the analysis of several directional permeability enhancement techniques mentioned above, it can be seen that the current coal seam permeability enhancement technology favors the diversified direction of multiple technologies acting in synergy, all of which play an effective role in the directional expansion of fractures to a certain extent. However, radial injection fracturing technology is mostly used in petroleum engineering, the difference between petroleum reservoir and coal seam cannot be ignored, and it is difficult to form longer radial holes in coal seam, so the guiding range is limited; while in the further study of non-homogeneous pore pressure guiding technology, it is found that long time pressure retention is required to form pore pressure field, and the guiding control is general; control hole guiding fracturing technology in engineering application needs to arrange a large number of boreholes. Compared with the above three, the cut-and-slit composite fracturing technology has the advantages of easy implementation and strong operability and controllability, and has a broad development prospect.

## 5. Conclusion

The safety and efficiency of mine mining are increasingly emphasized, which brings higher requirements for gas extraction technology. Compared with the conventional fracturing technology, the coal seam hydraulic fracturing directional penetration enhancement technology, especially the slit composite fracturing technology, overcomes the disadvantage of the "blank zone" of penetration enhancement on both sides of a single fracture in the direction of the maximum main stress, and greatly improves the efficiency of coal seam penetration enhancement; and the induction of directional expansion of hydraulic fractures, to a certain extent, avoids unnecessary damage to the top and bottom of the coal seam. The induction of the directional expansion of the hydraulic fracture can, to a certain extent, avoid unnecessary damage to the top and bottom of the coal bed. In the follow-up research, the following aspects can be studied.

①In the process of analyzing the gas transport pattern of the coal body after fracturing, the flow characteristics of gas and water in the fracture are studied by considering the effect of the intersection interface between gas and water.

②The current experimental research on slit-guided fracturing mostly starts from the slit deviation angle and horizontal stress difference coefficient, while the research on the effective range of action of slit length and arrangement spacing on fracture holes and applicable conditions is not sufficient.

③For the problem of improving the effective extension efficiency of fractured joints in the coal-rock complex production seam, the research on the formation mechanism of three-dimensional fracture network system of guided segmental fracturing is carried out to investigate the evolution law of stress field in the process.

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