Research on Anti-Reflection Technology of Coal Seam by Hydraulic Fracturing

Cheng Qian
School of Safety Science and Engineering, Henan Polytechnic University, Jiaozuo 454000, Henan, China

Abstract: As one of the key technologies of coal mine gas extraction and coalbed methane development in China, the anti-reflection technology of hydraulic fracturing coal seam is of great significance for improving the gas extraction amount of low permeability coal seam, reducing the risk of coal outburst, and promoting the effective mining of coalbed methane. By injecting high pressure water into the coal seam, the technology uses the pressure transmission of water to form a crack network in the coal seam. These cracks not only increase the permeability of the coal seam, so that the gas in the coal seam can flow more smoothly, but also communicate the natural cracks in the coal seam, and further improve the desorption and transport efficiency of gas. The application effect of hydraulic fracturing technology is remarkable. In some coal mines, through the implementation of hydraulic fracturing technology, the overall pressure relief and gas permeability of coal body are greatly improved, gas is released, and the total amount of extracted gas is significantly increased, which promotes the effective mining and utilization of coalbed gas. As a kind of unconventional natural gas resources, coalbed methane has great development potential. As a gas extraction and coalbed methane development technology with broad application prospects, hydraulic fracturing coal seam anti-reflection technology is of great significance for ensuring coal mine production safety, reducing gas accident incidence and promoting the effective exploitation and utilization of coalbed methane.
***Keywords*:** hydraulic fracturing, anti-reflection of coal seam, coalbed methane, gas extraction

1. Introduction

Coalbed methane (CBM), as a clean energy resource, is playing an increasingly vital role in the global energy structure. To enhance the efficiency of CBM extraction and utilization, hydraulic fracturing has emerged as a critical permeability-enhancing technique. By injecting high-pressure fluid to create and propagate fractures in coal seams, this technology significantly improves gas permeability, thereby enabling more sustainable and efficient CBM development as well as methane drainage[1-3]. This study aims to provide an in-depth investigation into the application of hydraulic fracturing in coal seam stimulation, exploring its potential contributions to boosting production and improving gas safety in mining operations[4].

Globally, hydraulic fracturing technology has been extensively employed in the coalbed methane (CBM) industry with remarkable achievements. However, as CBM development scales up, numerous challenges and unresolved issues remain regarding in-depth research and practical application of hydraulic fracturing for coal seam permeability enhancement. This study systematically examines the fundamental principles of hydraulic fracturing while addressing the practical requirements of CBM development, with particular focus on its critical applications in production enhancement and mine gas safety improvement. Through comprehensive analysis of hydraulic fracturing implementation in coal seam stimulation, this research aims to provide scientifically validated and effective technical solutions to facilitate efficient exploitation of CBM resources. Prevention strategies for coal and gas outbursts can be categorized into regional control measures and local control measures, with the former mainly consisting of protective seam extraction and advance gas drainage from coal seams[5-6].

To significantly improve gas drainage efficiency in low-permeability coal seams, current primary measures include increasing borehole density and extending gas extraction duration. Beyond these conventional approaches, various forms of “pressure relief and permeability enhancement” technologies must be implemented to either interconnect existing fracture networks within coal seams or generate new fracture systems. These techniques substantially increase the density and extent of internal fractures, thereby enhancing the coal seam’s permeability coefficient and ultimately improving gas drainage performance. Based on experimental research conducted domestically and internationally, the main technical methods for coal seam permeability enhancement currently include: Deep borehole drilling in outburst-prone seams; Deep-hole presplitting blasting; Hydraulic fracturing for permeability enhancement; High-pressure water jet borehole enlargement; Hydraulic slotting for permeability improvement[7-8].

2. Fundamental Principles of Hydraulic Fracturing Technology

The fundamental mechanism of hydraulic fracturing involves injecting high-pressure fluid into target formations to induce fracture initiation, creating either vertical or horizontally oriented fracture networks. Proppants are typically added to the fracturing fluid to maintain fracture aperture by preventing closure of newly generated fracture[9-10]. The theoretical framework of hydraulic fracturing primarily comprises two critical phases: fracture initiation and fracture propagation.

2.1 Fundamentals of Fracture Mechanics in Hydraulic Fracturing

Hydraulic fracturing is a well stimulation technique that improves reservoir permeability through high-pressure fluid injection, primarily applied in oil and gas extraction. Specifically, the process involves injecting high-pressure fracturing fluid into the wellbore and forcing it into the target formation. When the fluid pressure exceeds the formation's fracture pressure, the rock ruptures, creating one or more fractures. The initiation and propagation of these fractures constitute the core mechanism of hydraulic fracturing, as they establish new flow pathways for reservoir fluids.

Following fracture formation, proppant-laden fluid (carrying agents such as quartz sand) is continuously injected. The proppants function to maintain fracture aperture by preventing closure due to stress relaxation. As the slurry enters the fractures, it serves two critical purposes.

2.2 Fracture Propagation Mechanics

Hydraulic fracturing technology has demonstrated remarkable effectiveness in improving the low permeability of coal seams, increasing gas drainage volumes, reducing coal and gas outburst risks, and enhancing working face conditions. This technique has established a novel approach for regional gas control and coalbed methane (CBM) development in single, low-permeability coal seams[11]. While research on the fundamental mechanisms of hydraulic fracturing remains relatively limited, existing studies have provided a viable technical framework for water injection fracturing in coal seam boreholes. Extensive field tests reveal significant variations in fracturing effectiveness across different mining areas, coal seams, and geological conditions. Under optimal conditions, the permeability coefficient of fractured coal seams can increase by several orders of magnitude (100-1000 times), whereas in less favorable scenarios, the enhancement in gas permeability may be negligible or non-existent[12].

3. Current Research Status of Hydraulic Fracturing Technology

In recent years, China has made significant progress in hydraulic fracturing technology through a series of experimental studies and field applications. Continuous optimization of fracturing fluid formulations and operational parameters has substantially improved technical performance. Scholars Guo Qiwen, Zhang Wenyong et al[13] investigated the fracturing and fragmentation mechanisms in coal seam extraction via laboratory and field studies. Their findings indicate that hydraulic fracturing can generate micro-fractures within coal seams while creating localized stress concentration zones around these fractures. Kang Hongpu et al[14] systematically analyzed the influence of coal seam structure on hydraulic fracturing behavior, proposing a geometric model for fracture propagation based on empirical fracture pattern analysis. Regarding fracturing mechanisms, domestic researchers have conducted extensive studies on applications such as water-reducing agent fracturing in petroleum systems and permeability enhancement in coal mining.

4. Existing Challenges in Hydraulic Fracturing Technology

Extensive theoretical research and field practice have demonstrated that the effectiveness of hydraulic fracturing in coal seams depends not only on the fracturing techniques and methods employed, but also, to a significant extent, on the inherent fracturability of the target coal seam itself. This fracturability refers to whether the coal mass can undergo deformation and fracture development under high-pressure water injection in boreholes that are conducive to enhancing gas permeability, including whether the induced fractures can propagate extensively and remain open for a sustained duration. The suboptimal performance of hydraulic fracturing technology in many mining areas and coal seams is primarily attributed to the lack of prior understanding of the fracturing characteristics of different target formations (coal or rock). Without proper consideration of site-specific underground conditions and blind adherence to previously successful case studies, the implementation of hydraulic fracturing techniques often suffers from substantial uncertainty and randomness, severely compromising operational effectiveness and potentially leading to complete failure.

5. Conclusion

With the increasing development of coalbed methane resources and the continuous improvement and optimization of hydraulic fracturing technology, the field of coal seam permeability enhancement has shown unprecedented broad devel-

opment prospects. Coal seam anti permeability technology, as an important measure to respond to the national construction of a coordinated development mechanism for coal and coalbed methane, perfectly meets the urgent need for coal mine gas extraction standards. It has become a core technical means to prevent gas disasters and significantly improve gas extraction efficiency in the coal mining industry, and its application prospects are extremely optimistic.

The continuous progress and rapid development of this technology can not only effectively improve the technological level of mine gas prevention and control in China, but also significantly enhance the independent innovation capability of the coalbed methane industry, injecting strong impetus into the transformation and upgrading of the entire industry. Looking back at the past, a large amount of research and practical application work has been carried out in China, laying a solid foundation for the continuous improvement of coal seam anti permeability technology. These studies not only deepen our understanding of the anti transparency mechanism, but also promote significant improvements in the level of related equipment.

References

[1] ZHANG Hong, XIA Yujing, ZHANG Qun, et al. Geological conditions and comprehensive exploration of deep coal deposits: Current situation and problems [J]. Coal Geology and Exploration,2009,37(01):1-11+16.

[2] National Natural Science Foundation of China, Chinese Academy of Sciences, Energy Science Discipline Development Strategy Research Group. Report on China's Energy Science Discipline Development Strategy from 2011 to 2020.2010.

[3] WU Xiaodong, XI Changfeng, WANG Guoqiang. Research on fracture model of coalbed methane Wells with complex hydraulic fracturing [J]. Natural Gas Industry,2006(12):124-126+206-207.

[4] WANG Xianzheng. New Technology of Coal mine Safety [M]. Beijing: Coal Industry Press,2002.

[5] Ministry of Coal Industry, People's Republic of China. Regulations on Prevention and control of coal and Gas outburst [M]. Beijing: Coal Industry Press,2009.

[6] LV Youchang. Application of hydraulic fracturing technology in high gas and low permeability mines [J]. Journal of Chongqing University,2010,33(07):102-107.

[7] PENG Suping. Study status and future development trend of occurrence rule and geological evaluation of deep coal resources [J]. Coal,2008(02):1-11+27.

[8] ZHANG Yi, ZHOU Weidong, WANG Ruihe, et al. Design of hydraulic self-rotating jet drill in coal seam [J]. Natural Gas Industry,2008(03):61-63+141.

[9] WANG Han. Numerical simulation of vertical fracture morphology and fracture height control in hydraulic fracturing [D]. University of Science and Technology of China,2013.

[10] CHEN Liuwu, YANG Guohe, HUANG Chunming, et al. Hydraulic fracturing hole improves gas drainage effect of soft and low permeability coal seam [J]. Mining Safety and Environmental Protection,2009,36(S1):109-110.

[11] TANG Jianxin, JIA Jianqing, HU Guozhong, et al. Design and test of high pressure water jet device for coal seam in drilling [J]. Rock and Soil Mechanics,2007(07):1501-1504.

[12] ZHAO Yangsheng, YANG Dong, HU Yaoqing, et al. Research on effective technical ways of coalbed methane exploitation in low permeability coal reservoirs [J]. Journal of China Coal Society,2001(05):455-458.

[13] ZHANG Wenyong, SI Lei, Guo Qiwen, et al. Research on anti-reflection mechanism and application of liquid nitrogen injection fracturing in coalbed methane Wells [J]. Coal Science and Technology,2019,47(11):97-102.

[14] DU Yifang. Current situation and development of hydraulic fracturing technology abroad [J]. Journal of Xi 'an Shiyou Institute (Natural Science Edition),1994(02):26-29+20.