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Research Status and Progress of Water Lock Effect

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Abstract: Hydraulic fracturing can effectively improve the air permeability of the coal seam and improve the gas extraction rate, but in the later stage of gas extraction, the water trapped in the coal blocks the gas migration. In order to deeply study the water-lock effect after coal seam hydraulicization measures, this paper summarizes the research status of the causes of the water-lock effect, the influencing factors of the water-lock effect, and the methods of mitigating or eliminating the water-lock effect, analyzes the existing problems in the current research, and puts forward the direction that needs to be strengthened.

Keywords: Mechanical engineering; Manufacturing technology; Electrical automation.

1. Introduction

As one of the main hazards of coal mines, gas has always been a hot issue for scholars. With the intensification of global warming and the sharp decline in non-renewable energy reserves, more scholars are no longer limited to the treatment of mine gas accidents, but gradually change the focus of gas from disaster prevention to natural resource extraction. In the process of coal development, for coal resources containing more than a certain degree of coalbed methane, the content of gas in the coal seam should be reduced according to the principle of "gas mining first, coal mining later" to ensure that the safety standards are met before coal mining[1]. Gas extraction technology is an effective way to solve the problem of gas overrun and prevent the danger of coal and gas outburst. China's coal seams are basically characterized by "three lows and one high", that is, low pressure, low permeability, low saturation and high degree of metamorphism, which are particularly difficult to develop and utilize[2-4]. Hydraulic permeability enhancement is the most widely used permeability enhancement technology, which mainly includes hydraulic fracturing technology[5], water jet slitting technology[6], and punching technology[7]. Hydraulics measures can improve the permeability of coal seams, increase the gas seepage rate, and effectively improve the gas extraction rate. Coal is a porous medium with dense internal micropores, and while the hydraulicization method increases the permeability of the coal seam, the water enters the pores of the coal, and the capillary force in the micropores causes the water to remain in the coal body to form a water lock effect, which affects the migration of gas, and then affects the permeability enhancement effect[8-12].

2. The Cause of The Water Lock Effect

If the pressure difference between the inside and outside of the pore is not enough to overcome the capillary resistance, it is difficult for the gas to move outward, that is, the water lock effect is formed. It is generally believed that the porous medium characteristics of coal are the natural conditions for the formation of water locks. External liquid intrusion is the material condition for the formation of water locks; The pressure difference between the inside and outside of the pore is not enough to overcome the capillary resistance and is a pressure condition formed by the water lock. There are many microscopic pores and a large proportion of pore volume in high-metamorphic coal, and the capillary force of water in the pores of coal is large, resulting in a serious water-lock effect of high-rank coal. The trapped water trapped in the coal body blocks the gas flow channel, which is the cause of the water locking effect [13-16]. Huang Lingang [17] used molecular dynamics methods to study that the presence of water inhibits the diffusion of methane, resulting in a water-lock effect. By enhancing the interaction between water molecules and coal seams, it may be beneficial to alleviate the water lock effect. Tang Hai et al. [18] analyzed the natural cores and found that the types and contents of clay minerals and reservoir permeability were the internal factors affecting the waterlock effect, and the production pressure difference was the external factor affecting the waterlock effect. Zhang Guohua et al. [19] analyzed the water lock mechanism and concluded that the water lock effect is related to the characteristics and pressure conditions of the coal itself.

3. Influencing Factors of The Water-lock Effect

The influencing factors of the water lock effect are mainly affected by the surface tension of the solution, the contact angle between the coal and the solution, and the pore characteristics of the coal.

The expression for capillary force is given below:

$$Pc=2\sigma \cos\theta / r1 \quad (1)$$

where:
P_c is the capillary force, Pa;
σ is the surface tension of the solution, mN/m;
θ is the contact angle, (°);
r_1 is the capillary radius, nm.

3.1. Solution surface tension

As can be seen from Equation (1), the greater the surface tension of the solution, the greater the capillary force, the greater the resistance to the reverse discharge of the solution, the easier it is to stay in the coal, and the more serious the water lock effect. Capillary pressure can be reduced by selecting surfactants with low surface tension and reducing the resistance to the reverse discharge of the solution.

3.2. The angle of contact between the coal and the solution

The coal-water contact angle θ is used as an index to judge the type of surface wetting of the coal body. The closer θ is to 90°, when the coal surface is moderately gas-wetted, the closer the capillary pressure is to 0, and the easier it is to remove the water lock. The closer θ is to 0, that is, when the surface of the coal is water-wetted, the greater the capillary pressure and the more serious the water-lock effect. When a hydrophilic surfactant is applied to coal, the surface tension of the liquid decreases, but at the same time, it may cause theta to approach 0. Therefore, scholars have proposed to study the severity of the water-lock effect and select the appropriate surfactant based on σ cosθ, and believe that the closer the σ cosθ is to 0, the smaller the capillary pressure, and the easier it is to eliminate the water-lock. When θ is greater than 90°, that is, when the coal surface is gas-wetting, the σ cosθ is less than 0, and the capillary pressure changes from the resistance of liquid outward discharge and gas desorption to driving force, which is conducive to reducing water lock and promoting gas desorption.

3.3. Pore characteristics of coal

The pore size of coal, the pore size of coal pores, pore size distribution, pore shape and other pore characteristics will affect the severity of the water lock effect. It can be seen from equation (1) that the smaller the pore size, the greater the capillary pressure, the more serious the water lock effect, and the more difficult the gas extraction. The pore characteristics of coal are one of the main factors affecting the storage and migration of gas in coal, and the pores can be divided into closed pores, semi-closed pores, cross-linked pores and through pores according to the connectivity of the pores in coal, and according to the shape of the pores, they can be divided into layered pores, columnar pores, inkwell pores, conical pores and interstitial pores. Among them, shrinkage pores such as inkwell holes and interstitial holes are important factors that cause the Jia Min effect and water to block the pores.

4. Methods for Mitigating or Eliminating the Water-lock Effect

4.1. Physical methods

The physical methods of mitigating or eliminating water locks are mainly measures such as enhanced drainage, pressurized mining, and heat treatment. By increasing the drainage rate of fracturing fluid during the extraction process, the permeability of the reservoir can be maintained at a certain level and the formation of water lock effect can be inhibited. In addition, by reasonably increasing the negative pressure of pumping, the gas blocked by water is easier to discharge, so as to improve the gas extraction rate. The heating measures will accelerate the evaporation rate of the trapped water and the trapped water in the coal seam, thereby reducing the damage of the water lock. At the same time, increasing the temperature is conducive to the desorption of adsorbed gas and the increase of gas desorption. Ni Guanhua et al. [20] concluded from the two aspects of pore negative pressure and surfactant that increasing the pore negative pressure can eliminate the sealing of coal seam pores by water and eliminate the water lock effect. Anionic and nonionic surfactant solutions can relieve the water lock effect of coal.

4.2. Chemical methods

The chemical method of mitigating or eliminating water locking is mainly to attenuate the water lock effect by adding an appropriate surfactant to the fracturing fluid. Surfactants can reduce the surface tension of fracturing fluids, and at the same time reduce the contact angle formed on the coal surface, improve the wettability of the reservoir, and inhibit the water-lock effect. Song Jinxing et al. [21-22] found that surfactant fracturing fluid can reduce the pore capillary pressure of coal reservoirs, effectively promote the flowback of fracturing fluid, and reduce the damage of water lock to the permeability of coal reservoirs. Qin et al. [23] found that the addition of biosurfactants could effectively reduce the capillary self-priming of hypotonic cores, with a maximum reduction of 78.49%. Zheng Yangfeng [24] calculated the capillary force between seven surfactant fracturing fluids and the pore wall of the coal by adding surfactants to the fracturing fluid to relieve the water lock effect, and the results showed that the anionic surfactant SDBS was the best choice to reduce the capillary force. Hu Youlin [25] took the No. 3 coal sample in Qinshui Basin, Shanxi Province as the research object, and optimized the waterproof lock agent FSSJ, and the results showed that FSSJ has the characteristics of weak foaming, which can effectively reduce the surface tension, increase the contact angle, reduce the self-absorption of the coal core, and reduce the damage of the water lock in the coalbed methane reservoir, and has a good waterproof lock effect. Liang Li [26] synthesized a twin cationic surfactant, which was verified by field experiments to significantly reduce the damage to coal reservoirs. Su et al. [27] compounded surfactants with KCl, which can effectively improve the permeability of coal, which is conducive to coalbed methane extraction.

4.3. The problem exists.

At present, most of the methods related to reducing and eliminating water locks are carried out by experimental methods, and there is a lack of practical application in the field, and the application effect in engineering needs to be further investigated. The descriptions of the impact of water lock are all qualitative analysis at the macro level, and there is a lack of unified evaluation criteria, and further research is needed on mitigation or mitigation measures under different water lock degrees. The application of gas wetting inverter in coal seam water decomposition lock needs further research.

5. Summary

5.1. Summary

(1) The water lock effect is mainly due to the retention of foreign liquid in the coal, which blocks the channel of gas migration and inhibits the desorption of gas.

(2) There are many influencing factors of the water lock effect, and the main influencing factors are the surface tension of the foreign liquid, the contact angle between the coal and the solution, and the pore characteristics of the coal. These factors affect the degree of water locking by influencing the capillary force of the foreign liquid in the coal body.

(3) Methods such as surfactants and increasing the negative pressure of pores can effectively reduce or alleviate the water lock effect.

5.2. Hasdfhask

Conflicts Of Interest

The authors declare that they have no conflict of interest.

References

[1] Wang Yonglong, Pei Yuxiang, Sun Yuning, et al .Gas gushing damping mechanism and its engineering application of bottom hole[J/OL]. Journal of China Coal Society:1-8[2023-02-19]. https://doi.org/10.13225/j.cnki.jccs.2022.1370.

[2] YUAN Liang. Scientific Thinking and Countermeasures for the Development and Utilization of Coalbed Methane in China[J]. Science & Technology Review, 2011, 29 (22): 3.

[3] Li Y, Zheng Rui, Luo Kai, et al.Reasons of low yield and stimulation measures for CBM wells in Junlian area[J]. Coal Geology & Exploration,2020,48(04):146-155.

[4] Zhi-Rong W , Zhong-Yang H , Shu-Kai L I ,et al.Coupling characteristics of soft coal fracture damage and coalbed methane seepage under water fracturing condition[J].Journal of Henan Polytechnic University(Natural Science), 2014.33(02):125-131. https://doi.org/10.16186/j.cnki.1673-9787.2014.02.009.

[5] S. Zhu,A. Salmachi,Z. Du. Two phase rate-transient analysis of a hydraulically fractured coal seam gas well: A case study from the Ordos Basin, China[J]. International Journal of Coal Geology,2018,195. https://doi.org/10.1016/j.coal.2018.05.014.

[6] Su D.,Kang Y.,Yan F.,et al. Crack Propagation Law Affected by Natural Fracture and Water Jet Slot under Blast Loading[J]. Combustion, Explosion, and Shock Waves,2018,54(6). https://doi.org/10.1134/S0010508218060151.

[7] Lu Yiyu, Huang Shan, Ge Zhaolong, et al.Research progress and strategic thinking of coal mine water jet technology to enhance coalpermeability in China[J].Journal of China Coal Society,2022,47(09):3189-3211. https://doi.org/10.13225/j.cnki.jccs.SS22.0602.

[8] Wang Zedong, Liu Guolei, Cui Y, et al.Pressure relief and permeability enhancement technology of gas-liquid composite fracturing in low permeability coal seam[J]. Safety in Coal Mines,2022,53(11):76-82. https://doi.org/10.13347/j.cnki.mkaq.2022.11.014.

[9] Zhou Lei, Peng Yu, Lu Yiyu, Xia Binwei.Numerical simulation of deep CBM hydraulic slotting pressure relief and desorption and permeability enhancement based on the MPM[J]. Journal of China Coal Society,2022,47(09):3298-3309. https://doi.org/10.13225/j.cnki.jccs.SS22.0898.

[10] Yang M, Xu J, He M, et al. Distribution and transport law of polymorphic water in coal body under infiltration environment[J/OL].Journal of China Coal Society:1-9[2023-02-19]. https://doi.org/10.13225/j.cnki.jccs.2022.0870.

[11] Li Yong, Xu Lifu, Liu Yu, et al.Occurrence mechanism, environment and dynamic evolution of deep coalbed methane water[J].Coal Geology & Exploration,2024,52(02):40-51.

[12] Zheng Chao, Ma Dongmin, Chen Yue, et al.Research progress micro effect of water on coalbed methane adsorption/desorption[J].Coal Science and Technology, 2023, 51(02): 256-268.) https://doi.org/10.13199/j.cnki.cst.2022-1537.

[13] Liu Qian, Huang Jianbin, Ni Guanhua, et al. Experimental study on low-field nuclear magnetic resonance (NMR) of liquid phase intrusion effect of different coal grades[J].Journal of China Coal Society,2020,45(03):1108-1115.) https://doi.org/10.13225/10.13225/j.cnki.jccs.2019.1354.

[14] Zhang Xuejie, Chen Mingyi, Zhang Tonghao, et al. Research progress of surfactantaqueous solution inhibiting the desorption of gas in coal [J].Journal of Mining Science, 2022, 7(06): 738-751.

[15] Qin Yujin, Su Weiwei, Tian Fuchao, et al.Research status and development direction of microcosmic effect under coal seam water injection[J]. Journal of China University of Mining and Technology,2020,49(03):428-444. https://doi.org/10.13247/j.cnki.jcumt.001148.

[16] Xie Xiangxiang, Zhang Yugui, Jiang Jiayu, et al.The influence of drilling fluid on coal bed methane desorption loss of coal core[J].Coal Geology & Exploration,2015,43(01):30-34+42.

[17] Huang Lingang, Lin Ling, Luo Wenjia.Molecular dynamics study on methane diffusion and water lock effect in coalbed methane[J].Journal of China Coal Society,2023,48(11):4124-4134. https://doi.org/10.13225/j.cnki.jccs.2022.1860.

[18] Tang Hai, Lv Jianjiang, Lv Dongliang, et al. Study on the influencing factors of water lock in tight and low-permeability gas reservoirs [J]. Journal of Southwest Petroleum University (Natural Science Edition), 2009,31 (04): 91-94+204

[19] Zhang Guohua, Lu Ting, Liang Bing, et al. Theory of Gas Overlimit Prevention and Control Based on Water Lock Mechanism [J]. Journal of Heilongjiang University of Science and Technology, 2010,20 (02): 103-106

[20] Ni Guanhua, Li Zhao, Jie Hongchao. A method for releasing the lock up effect of coal seam water based on nuclear magnetic resonance testing [J]. Journal of Coal Science, 2018, 43 (08): 2280-2287. https://doi.org/10.13225/j.cnki.jccs.2017.1324.

[21] Song Jinxing, Yu Shiyao, Su Xianbo, et al. Experimental Study on the Mechanism of Waterproofing and Increasing Production of Surfactant Fracturing Fluid [J]. Coalfield Geology and Exploration, 2019,47 (02): 98-102

[22] Song Jinxing, Chen Peihong, Wang Qian. Experimental screening of surfactants for water-based fracturing fluids in coal reservoirs [J]. Coalfield Geology and Exploration, 2017,45 (06): 79-83

[23] Qin Jianjian, Xue Yuzhi, Pei Meishan, et al. Laboratory study on water locking by biosurfactants [J]. Drilling and completion fluids, 2010,27 (06): 8-11+95

[24] Zheng Yangfeng, Zhai Cheng, Ni Guanhua. Research on the Performance of Fracturing Fluids Based on Surfactants to Relieve Water Locking Effect [J]. Coal Mine Safety, 2019,50 (11): 1-5. https://doi.org/10.13347/j.cnki.mkaq.2019.11.001.

[25] Hu Youlin, Wu Xiaoming. Research on the mechanism of water blocking damage in coalbed methane reservoirs and waterproof locking agents [J]. Journal of Coal Science, 2014,39 (06): 1107-1111. https://doi.org/10.13225/j.cnki.jccs.2013.1024.

[26] Liang Li, Guan Baoshan, Liu Ping et al. Application of Gemini Cationic Surfactant Fracturing Fluid in Coalbed Methane Wells [J]. Coal Science and Technology, 2016,44 (05): 112-115+182 https://doi.org/10.13199/j.cnki.cst.2016.05.022.

[27] Su X, Wang Q, Song J, et al. Experimental study of water blocking damage on coal[J]. Journal of Petroleum Science and Engineering, 2017, 156: 654-661.