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Experimental Study on the Influence of Coal Fracture Surface Roughness on Water Injection Seepage

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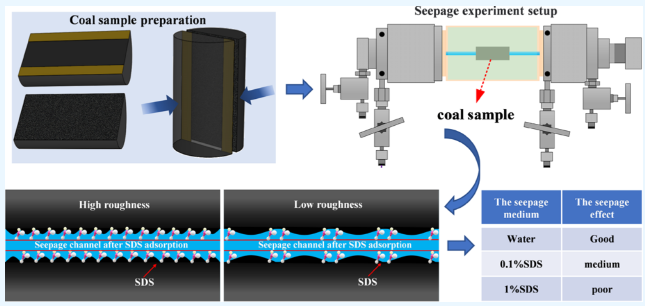
Cite This: *ACS Omega* 2022, 7, 32679–32689

ABSTRACT: Coal seam water injection has a significant effect on downhole dust resistance. However, during the operation of coal seam water injection, the seepage of the solution in the coal fractures is impacted by the roughness of coal fractures. Therefore, in this study, distilled water and a sodium lauryl sulfate surfactant were used as seepage solutions, kennel coal was used as the research subject, and four coal samples with different roughness coefficients were prepared for seepage experiments. After the analysis and discussion of the experimental results, it is found that the surface roughness of coal fractures hinders the seepage effect of coal seam water injection. The greater the surface roughness of coal fractures, the smaller the permeability coefficient. Furthermore, increasing the injection pressure and fracture aperture can reduce the influence of coal fracture surface roughness on the permeability coefficient. In addition, after sodium lauryl sulfate is added, the permeability coefficient of the coal sample is reduced. This further reveals the seepage of water injection into coal seams and provides certain guidance for the development of coal seam water injection technology.



1. INTRODUCTION

Coal is one of the world's three major resources. With the gradual depletion of shallow coal resources, deep coal mining has become an important development trend in the future. However, in the process of deep mining, there are many engineering disaster prevention and control problems such as rock bursts, floor water inrush, gas outbursts, and coal dust explosions.[1−4] Since coal seam water injection is an effective means to prevent outburst and suppress coal dust, it is widely used in coal fields.[5,6] In addition, coal seam water injection can increase the water content of the coal mass, change the nature of the coal mass, and reduce the dust concentration during the mining process, thereby reducing the hazards of dust to personnel health and engineering equipment.[7] However, the mechanism of the coal seam water injection process is complicated, and the actual parameter setting often depends on experiences. Therefore, it is necessary to study the effect of the surface roughness of coal seam pores and fractures on the seepage process of coal seam water injection. This is of great significance for improving coal seam water injection technology and ensuring coal mining safety.

The surface roughness of coal fractures is an important parameter that affects coal permeability. For the mechanism of the influence of surface roughness of coal fractures on seepage, a lot of research has been conducted at home and abroad. The joint roughness coefficient (JRC) was proposed by Barton (1973) as an empirical coefficient to express the influence of surface roughness and undulation on the surface shear strength of rock structure.[8,9] Barton et al.[10−12] put forward 10 standard profiles determined through JRC in 1982, which could better characterize the surface roughness of fractures and provide a theoretical basis for the subsequent research of the mechanism of seepage in rough fractures. Turk, Deannan et al.[13] proposed a direct measurement method to describe JRC and established an equation for the relationship between the undulation angle of rock mass structural surface and the JRC. Shen et al.[14] validated the model based on the lattice Boltzmann seepage−dissolution coupling relationship reflected on the surface of rock mass fractures through two classic numerical examples and studied the coupling mechanism of seepage−dissolution in rough rock fractures. They found that the larger the fractal dimension of the fracture wall, the rougher the geometrical morphology, the slower the convection and the diffusion speed of the solute, and the slower the seepage velocity. Cai et al.[15] summarized the basic characteristics of seepage in rough fractures and related research results and believed that fracture width and surface roughness would affect fracture seepage characteristics, and that fracture width and surface roughness

Received: July 8, 2022
Accepted: August 22, 2022
Published: September 1, 2022

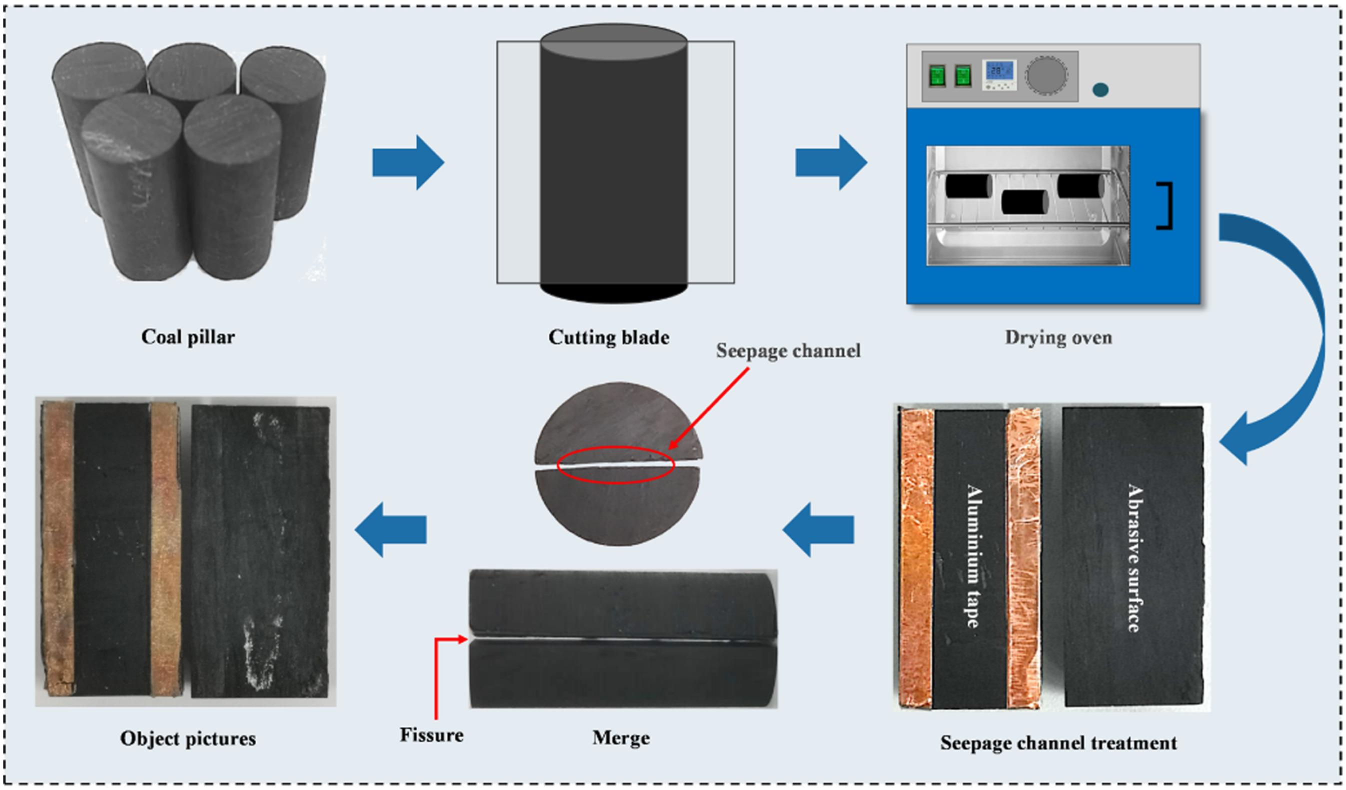


Figure 1. Preparation process of coal samples.

would also affect each other. Zhang et al.[16] developed a single rough fracture seepage model with different roughness coefficients (JRC) through numerical simulation software COMSOL. They reported that in the process of fluid seepage in a rough fracture channel, both the maximum flow velocity in the fracture and the average velocity at the outlet gradually decreased with the increase in the JRC value and that the roughness of the fracture had an obstructive effect on the seepage. Cui et al.[17] constructed fracture channels with rough joint surfaces based on the three-dimensional (3D) Weierstrass−Mandelbrot fractal function, obtained a transparent and fine fracture model through 3D printing technology, and studied the effect of fracture width and fractal dimension on the seepage characteristics of rock fractures. They pointed out that both the fracture width and the fractal dimension would cause the hydraulic gradient in the fracture channel to change. Zhang et al.[18] proposed that when the underground space of coal mine is used to construct underground reservoir, the influence of water solution seepage on reserved coal pillar and surrounding rock may threaten the stability of the reservoir. Wang et al.[19] found through laboratory experiments that at low water injection pressure, adding 0.1 and 1% sodium dodecyl sulfate (SDS) surfactant solutions would actually hinder seepage, thereby reducing the permeability coefficient.

It is worth noting that many researchers focused their research on the influence of fracture roughness from a macro perspective, i.e., the influence of the degree of fracture surface undulation on the seepage in rock and coal fractures, and obtained the effect of rock and coal fracture joint surfaces on seepage characteristics.[20−24] However, there is still a lack of systematic research on the influence of the surface roughness of coal fractures on the seepage characteristics of water injection from the microscopic level, which limits the development of disaster prevention technology for water injection to a certain extent. Therefore, it is necessary to study the influence of the width and surface roughness of a single coal fracture on the seepage characteristics of water injection. In this paper, the long-flame coal from the Houwenjialiang Coal Mine in Ordos City, Inner Mongolia Autonomous Region, China, is taken as the research object, and the coal samples with different fracture surface roughness coefficients are prepared with sandpapers of different meshes. After different fracture apertures are manually set and surfactants are added, the changes in the fracture seepage characteristics are analyzed. Through the self-developed multiscale loading seepage system, the fracture seepage experiments are carried out under the conditions of constant axial pressure and confining pressure and changing liquid injection pressure, and the mechanism of multiscale influence of fracture surface roughness on coal seepage characteristics is explored. These findings can provide certain guidance for the development of coal seam water injection technology and the systematic study of the water injection seepage.

2. EXPERIMENTAL SECTION

2.1. Preparation of Coal Samples. The coring operation was first conducted on the long-flame coal from 60−70 m underground of the Houwenjialiang Coal Mine in Inner Mongolia, China. Next, a cylinder with a diameter of 25 mm and a height of 50 mm was taken out and cut into two parts along the center line of the coal pillar. A total of five half-cylinder coal samples were prepared for the experiment. Then, the five coal samples were ground with sandpaper of 7000, 120, 60, 46, and 36 mesh, respectively, to obtain different surface roughnesses. The smoothest coal sample was chosen as the reference and the platinum aluminum tape was pasted on it.

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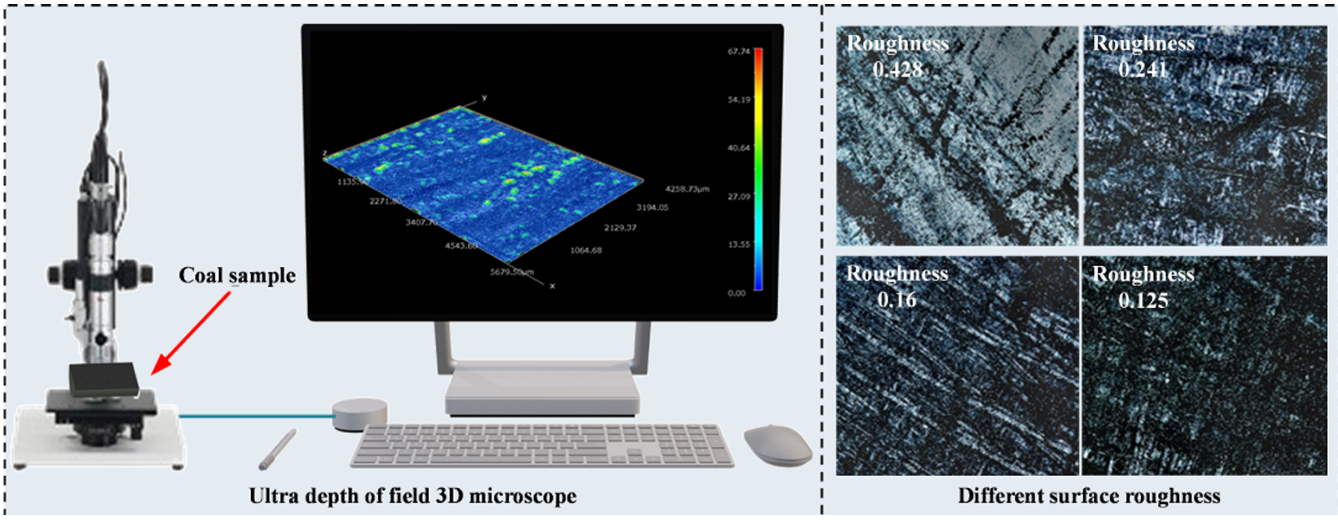

Figure 2. Microscopic structure and photos of fracture surfaces with different roughnesses.

After that, the remaining four coal samples were attached to platinum aluminum tape, respectively, to form a cylindrical coal sample with a rectangular fracture in the center of the coal pillar, as shown in Figure 1. In this experiment, different layers of platinum aluminum tape were used to adjust the fracture aperture. Finally, the coal samples with different fracture surface roughnesses required for the multiscale fracture seepage experiment were obtained.

To ensure the reliability of the experimental process and results, the coal samples were first put into a drying box with a drying temperature of 65 °C. After drying for 24 h, the coal samples were taken out and wrapped in plastic wrap for later use.

2.2. Microscopic Observation. In this experiment, a LEICA DVM5000 HD ultra-depth-of-field 3D microscope was used to scan the surface of the prepared coal sample to select points. The scanning area for each point is a square of 107.23 μm × 107.23 μm. To ensure the objectivity of the experiment, 10 areas on the surface of each coal sample were selected for scanning. Through the observation of coal samples polished by various specifications of sandpaper, the coal samples polished by 120, 60, 46, and 36 mesh were finally selected for experimental research. Figure 2 shows the photos of the coal crack surface with four different roughnesses.

Through the observation of the 10 selected areas on the surface of coal fractures, the 10-point height average *Rzjis*[25] of the microscopic surface irregularity of each coal fracture was recorded as the roughness coefficient, which was used as a quantitative indicator for the subsequent seepage analysis of the water injection effect. *Rzjis* is defined as the sum of the average of five contour peak heights (Y_p) and the average of five contour valley depths (Y_v) within the sampling length L on the center line of the roughness curve.

$$R_{zjis} = \frac{(Y_{p1} + Y_{p2} + Y_{p3} + Y_{p4} + Y_{p5}) + (Y_{v1} + Y_{v2} + Y_{v3} + Y_{v4} + Y_{v5})}{5} \quad (1)$$

The 10-point height average of microscopic surface irregularity of the 10 selected areas on the surface of the coal sample was calculated as the surface roughness coefficient of the coal fractures, as shown in Table 1.

2.3. Multiscale Loading Seepage System. The structure of the multiscale loading seepage system is shown in Figure 3.

Table 1. Surface Roughness Coefficients of Coal Fractures Ground with Sandpaper of Different Meshes

sandpaper mesh	120	36	60	46
roughness coefficient	0.428	0.241	0.16	0.125

The main purpose of the experiment is to study the influence of the surface roughness of coal fractures on the permeability coefficient under different liquid injection pressures at different fracture apertures. Through field research, it is learned that when coal seam water injection is used to prevent dust disasters in the Houwenjialiang Coal Mine, an SDS surfactant solution with a concentration of 0.1−1% will be added. Therefore, in addition to distilled water, an SDS surfactant solution with a concentration of 0.1 and 1% was selected as the seepage fluid in this experiment. Since the main purpose of this experiment is to explore the influence of the surface roughness of coal fractures on the permeability coefficient at the microscopic level, the injection pressure should not be set too high, and thus the injection pressure was set to three levels of 0.1, 0.2, and 0.3 MPa. In addition, because the seepage characteristics of coal seam water injection are different at different fracture apertures, the effect of coal fracture surface roughness on seepage may be different at different fracture apertures. To explore this, three fracture apertures of 0.06, 0.12, and 0.18 mm were set in the experiment to ensure the universal applicability of the experimental results. In this study, each fracture aperture corresponds to 27 groups of seepage tests.

Therefore, a total of 108 groups of seepage tests were designed in this study, as shown in Table 2. The experimental confining pressure and axial pressure were fixed at 5 and 1 MPa, respectively. The pressurization time for each experiment was set to 1 h. During each experiment, the injection flow and the cumulative flow were automatically recorded every 1 min by the system. The ambient temperature of the laboratory was maintained at a constant temperature of 25 °C (the temperature is consistent with the temperature of the outside atmosphere) to eliminate the error of the experimental results due to temperature factors. In addition, to ensure the reliability of the experimental data and eliminate the error caused by data fluctuation in the early seepage stage, the data after the

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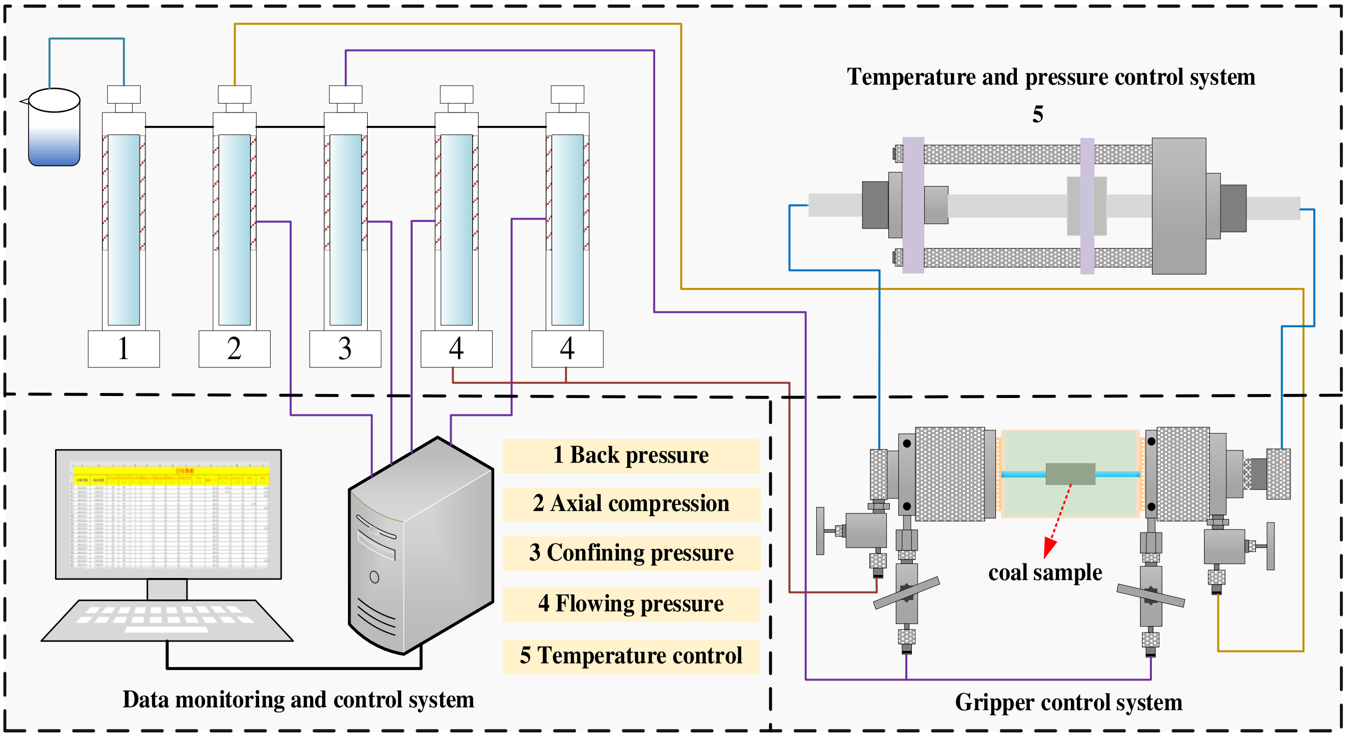

Figure 3. Structure of the multiscale loading seepage system.

Table 2. Design of Variables for Seepage Experiments of Coal Sample Fractures with Different Surface Roughnesses

no.	roughness coefficient	injection pressure (MPa)	fracture aperture (mm)	SDS (%)
1−108	0.428			
	0.241	0.1	0.06	0
	0.16	0.2	0.12	0.1
	0.125	0.3	0.18	1

injection flow reached a steady state were selected for fitting analysis.

In the past, researchers put forward many theories describing the conductivity of porous media, among which Darcy's law is the most classic and widely used. According to this law, the permeability coefficient can be used to characterize how easy it is for fluid to pass through fractures. The larger the permeability coefficient, the stronger the water permeability of the fracture, and vice versa[26−28]

$$K = \frac{QL\gamma}{pA} \tag{2}$$

where γ is the bulk density of water, kN/m^3; Q is the amount of water passing through the coal sample per unit time, m^3/s; L is the length of the coal sample, m; A is the cross-sectional area of the coal sample, m^2; and p is the pressure difference between the two ends of the coal sample, KPa.

3. RESULT ANALYSIS

3.1. Effect of Fracture Surface Roughness on the Seepage of Distilled Water in Coal Fractures. Figure 4 shows the results of the seepage experiments at different fracture apertures with distilled water as the seepage fluid. The green, blue, red, and black scattered points represent the

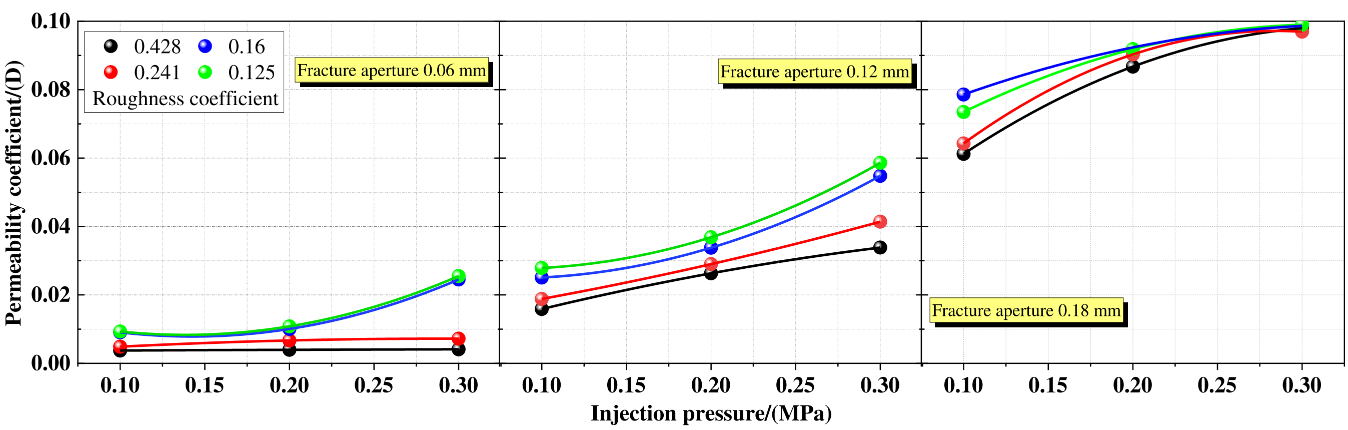

Figure 4. Influence of fracture surface roughness on the permeability coefficient of distilled water in coal samples.

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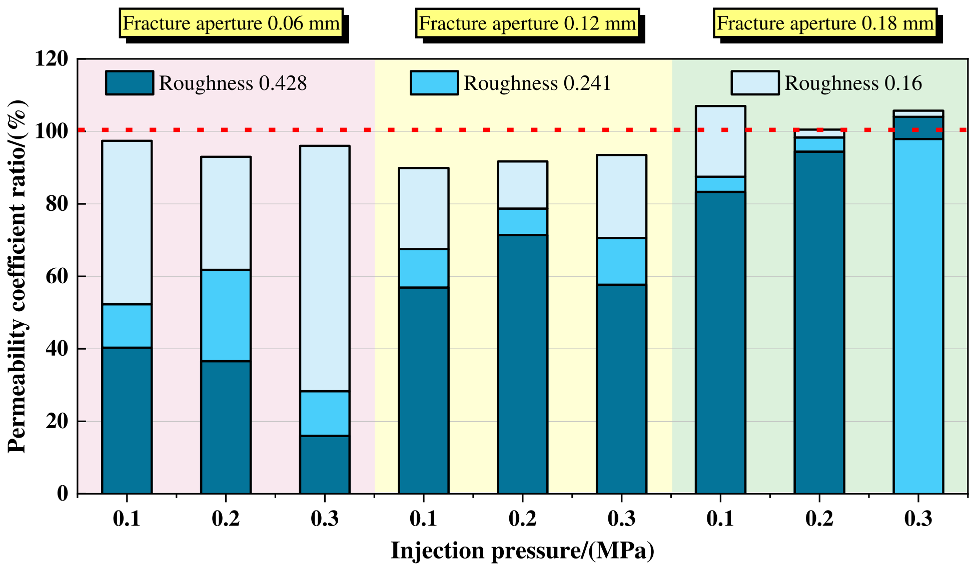

Figure 5. Permeability coefficient ratio of distilled water for different fracture surface roughnesses.

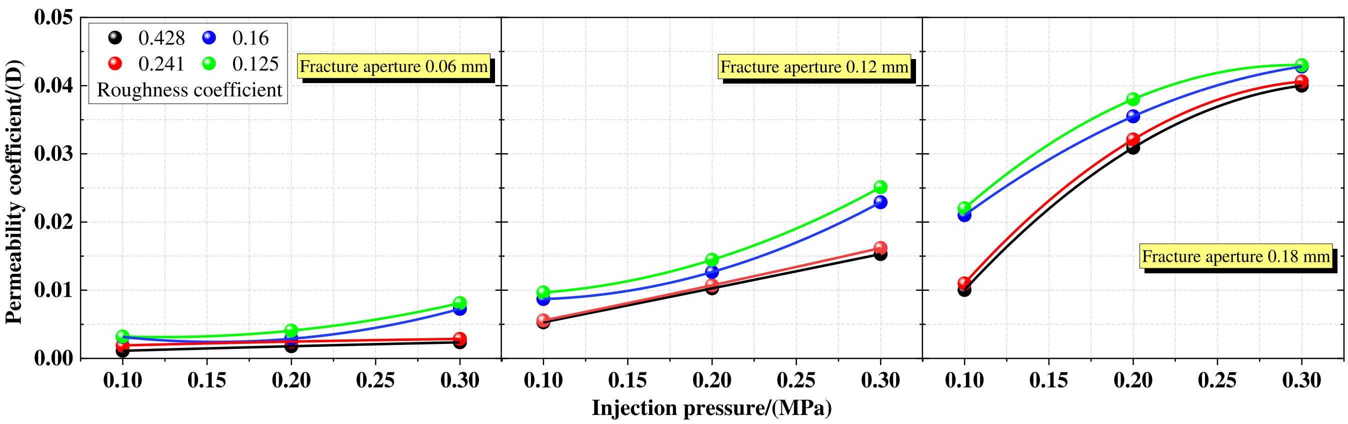

Figure 6. Influence of fracture surface roughness on the permeability coefficient of 0.1% SDS.

measured permeability coefficients of coal samples with the fracture surface roughness coefficients of 0.125, 0.16, 0.241, and 0.428, respectively, at three injection pressures.

As shown in Figure 4, when distilled water is used as the seepage fluid, the coal samples show two different seepage characteristics at the fracture apertures of 0.06 and 0.12 mm. The permeability coefficients of the coal samples with the fracture surface roughness coefficients of 0.428 and 0.241 increase as the injection pressure increases with a small increase rate, and the increase rate of the coal sample with a roughness coefficient of 0.428 is less than that of the coal sample with a roughness coefficient of 0.241. Similarly, the permeability coefficients of the coal samples with the fracture surface roughness coefficients of 0.16 and 0.125 also increase with the increase in the injection pressure but with a larger increase rate. This indicates that a rough coal fracture surface is more likely to affect the seepage process. When the fracture aperture reaches 0.18 mm, the permeability coefficients of the coal samples are still related to the surface roughness of the coal samples at an injection pressure of 0.1 MPa. However, the permeability coefficient of the coal sample with a roughness coefficient of 0.125 is smaller than that of the coal sample with a roughness coefficient of 0.16. This indicates that as the fracture aperture increases, the effect of fracture surface roughness on seepage decreases. At a fracture aperture of 0.18 mm, the permeability coefficients of the coal samples all show a slow rising trend. In addition, when the injection pressure is 0.3 MPa, the influence of fracture surface roughness on the permeability coefficient is significantly reduced. Therefore, both the fracture aperture and the liquid injection pressure have a certain impact on the seepage characteristics of coal samples with different fracture surface roughness coefficients.

Figure 5 shows the ratio of the permeability coefficient of the coal sample with the roughness coefficients of 0.16, 0.241, or 0.428 to the permeability coefficient of the coal sample with a roughness coefficient of 0.125 with the distilled water as the seepage fluid at three fracture apertures and three injection pressures. The red dashed line in Figure 5 represents the permeability coefficient of the coal sample with a roughness coefficient of 0.125. As indicated in Figure 5, with the increase in the fracture aperture, the difference between the permeability coefficient ratios of coal samples with different roughnesses decreases. In general, at the same fracture aperture and injection pressure, the greater the roughness, the smaller the permeability coefficient. In addition, with the increase in the injection pressure, the influence of fracture surface roughness on the seepage increases at the small openings of

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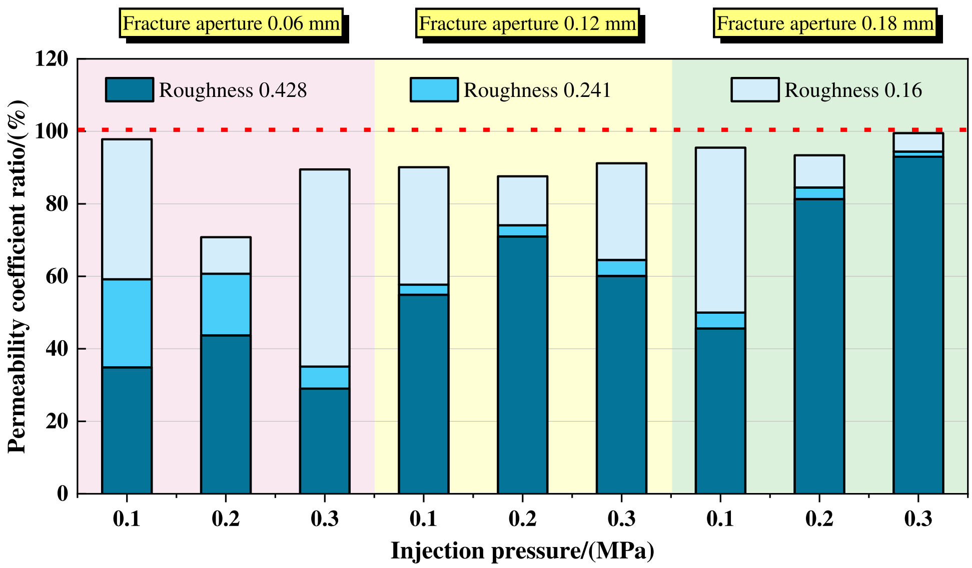

Figure 7. Permeability coefficient ratio of the 0.1% SDS solution for different fracture surface roughnesses.

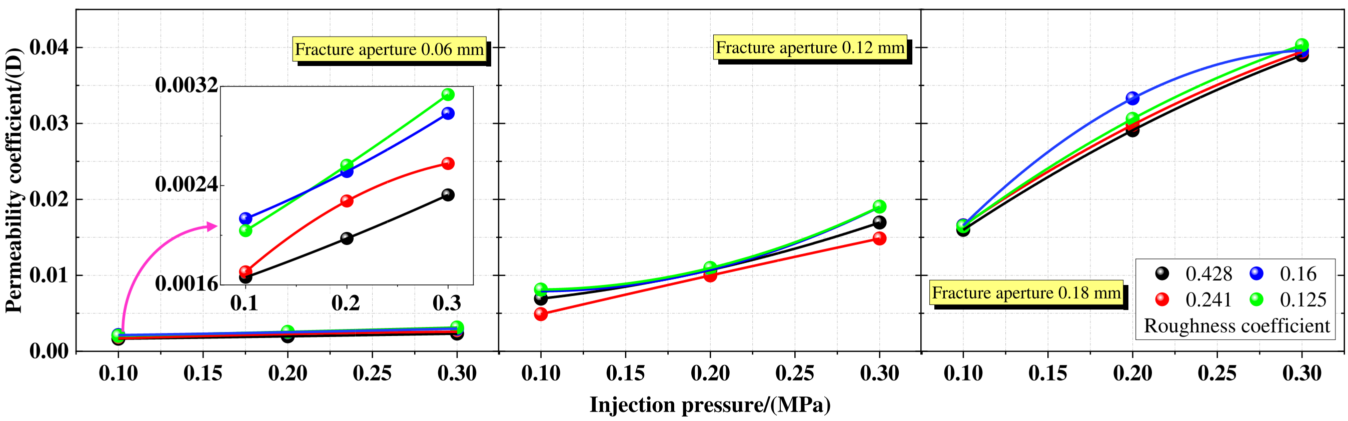

Figure 8. Effect of fracture surface roughness on the permeability coefficient of the 1% SDS solution.

0.06 and 0.12 mm but weakens at the large fracture aperture of 0.18 mm. This indicates that in the process of coal seam water injection, the effect of the surface roughness of coal fractures on the permeability coefficient can be reduced by increasing the water injection pressure and expanding the fracture aperture.

3.2. Effect of Fracture Surface Roughness on the Seepage of the SDS Surfactant Solution in Coal Fractures. Figures 6 and 8 show the results of the seepage experiments at different fracture apertures with 0.1 and 1% SDS solutions as the seepage fluid, respectively. Figures 7 and 9 show the ratio of the permeability coefficients of coal samples with three different roughnesses to that of the coal sample with a roughness coefficient of 0.125 with 0.1 and 1% SDS solutions as the seepage fluids, respectively.

Figure 6 shows the influence of fracture surface roughness on the permeability coefficient for seepage of a 0.1% SDS solution in coal fractures with the other conditions unchanged. It is obvious that the 0.1% SDS solution still follows the seepage law of distilled water but the permeability coefficient drops significantly. This indicates that the 0.1% SDS solution hinders the seepage process of coal seam water injection.

The data from 36 experiments with the 0.1% SDS solution as the seepage fluid are analyzed, and the permeability coefficient ratios of three coal samples with roughness coefficients of 0.428, 0.241, and 0.16 are plotted, as shown in Figure 7. With Figures 7 and 5 compared, at low injection pressure, the difference between the permeability coefficient ratios of coal samples for the 0.1% SDS solution is smaller than that for distilled water. Therefore, at low injection pressure, the influence of coal fracture surface roughness on the seepage of the 0.1% SDS solution is less than that of distilled water.

Figure 8 shows the experimental results with a 1% SDS surfactant solution used as the seepage fluid and the other experimental conditions unchanged. At a fracture aperture of 0.06 mm, the permeability coefficient is still affected by the fracture surface roughness of the coal sample, and the permeability coefficients of the four coal samples remain positively correlated with the injection pressure. When the fracture aperture reaches 0.12 mm, the permeability coefficients of the four coal samples are less affected by the surface roughness of the coal fracture, and the increase rate of the permeability coefficient with the increase in the injection pressure for the 1% SDS surfactant solution is less than those for distilled water and the 0.1% SDS solution. When the fracture aperture reaches 0.18 mm, except for the coal sample with a roughness coefficient of 0.428, the influence of the fracture surface roughness of the remaining three coal samples

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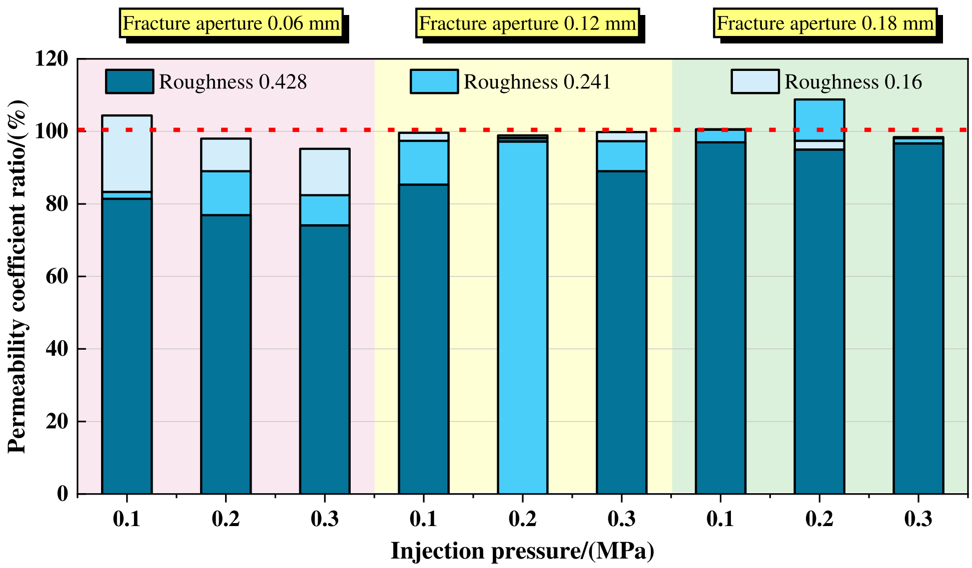

Figure 9. Permeability coefficient ratio of the 1% SDS solution for different fracture surface roughnesses.

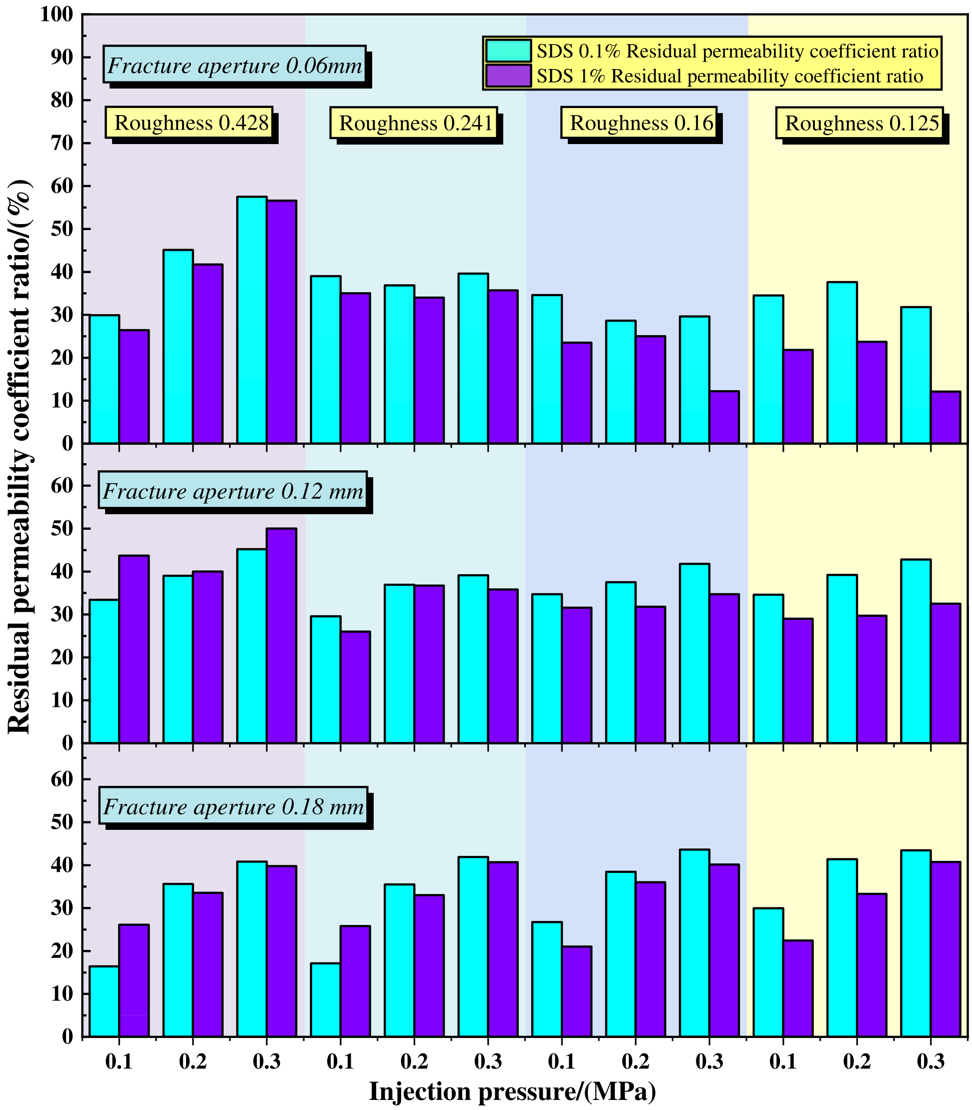

Figure 10. Residual permeability coefficient ratios of two SDS solutions for coal fractures with different roughnesses.

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on the permeability coefficient is negligible. For the 1% SDS solution, when the injection pressure increases, the effect of fracture surface roughness on the permeability coefficient does not change significantly compared with those for distilled water and the 0.1% SDS solution. However, the 1% SDS surfactant solution hinders the seepage process of coal seam water injection.

The 36 sets of experimental data with 1% SDS solution as the seepage fluid are analyzed, and the permeability coefficient ratios of three coal samples with roughness coefficients of 0.428, 0.241, and 0.16 are plotted, as shown in Figure 9. The difference between the permeability coefficient ratios for the 1% SDS solution at different fracture apertures and liquid injection pressures is significantly reduced when compared with those for distilled water and the 0.1% SDS solution. This indicates that a high concentration SDS solution is more sensitive to the roughness of coal fractures, and that it not only has an obstructive effect on the seepage in coal fractures with large roughness but also hinders the seepage in coal fractures with small roughness.

3.3. Hindrance of the SDS Solution to Seepage in Rough Fractures. Sodium dodecyl sulfate (SDS) is commonly used in coal seam water injection as a wetting agent. Many engineering experiences have shown that SDS can promote the wettability of the coal surface, thereby enhancing the water injection effect.[29] To further characterize the influence of an SDS surfactant solution on the seepage characteristics of coal samples, the residual permeability coefficient ratio proposed by previous researchers[18] is adopted in this paper, which is the ratio of the permeability coefficient of the SDS solution to the permeability coefficient of distilled water.

$$\eta = \frac{K_{\mathrm{SDS}}}{K_{\mathrm{water}}} \tag{3}$$

where η is the residual permeability coefficient ratio, %; K_{SDS} is the permeability coefficient of SDS solution; and K_{water} is the permeability coefficient of water.

By monitoring η during the injection of an SDS solution and comparing the experimental results at different fracture apertures and SDS concentrations, the influence of the SDS solution on the seepage in coal fractures is analyzed. At the three fracture apertures of 0.06, 0.12, and 0.18 mm, the residual permeability coefficient ratios of coal samples at different injection pressures are obtained, as shown in Figure 10. The blue and purple columns represent the residual permeability coefficient ratios of 0.1 and 1% SDS surfactant solutions, respectively.

At a fracture aperture of 0.06 mm, the SDS solution has greater damage to the permeability coefficient of the coal sample. The greater the injection pressure, the more obvious the damage of the high concentration SDS solution to the permeability coefficient of the coal sample. As shown in Figure 10, the residual permeability coefficient ratio of the coal sample with a roughness coefficient of 0.125 at an injection pressure of 0.3 MPa is only 12.1%.

When the fracture aperture is 0.12 mm, the residual permeability coefficient ratio of the SDS solution for the coal sample with a smooth fracture surface is relatively small at injection pressures of 0.2 and 0.3 MPa. However, under the same conditions, the residual permeability coefficient ratio of the coal sample with a smooth fracture surface at a fracture aperture of 0.12 mm is greater than that at a fracture aperture of 0.06 mm. This indicates that expanding the fracture aperture and increasing the water injection pressure can significantly improve the seepage effect of the SDS solution in coal fractures.

When the fracture aperture is 0.18 mm and the injection pressure is low, the high concentration SDS solution has a better seepage effect in the coal sample with high fracture roughness than the low concentration SDS solution, while the low concentration SDS solution has a better seepage effect in the coal sample with low fracture roughness than the high concentration SDS solution. When the injection pressure reaches 0.2 and 0.3 MPa, the two concentrations of SDS solutions have the same hindrance effect on seepage, and the residual permeability coefficient ratios of the four coal samples are all positively correlated with the injection pressure. This indicates that increasing the injection pressure can improve the effect of the SDS solution on the seepage of coal seam water injection at a large fracture aperture.

As indicated in Figure 10, when the injection pressure is high, the residual permeability coefficient ratio of the SDS solution is negatively correlated with the concentration of the SDS solution at the three fracture apertures. This is more obvious for the coal sample with a smooth fracture surface at a small fracture aperture. Therefore, it can be inferred that the permeability coefficient of the coal sample with a smooth fracture surface decreases with the increase in the concentration of the SDS solution at a small fracture aperture. To verify this inference, a seepage experiment is carried out at an injection pressure of 0.3 MPa and a fracture aperture of 0.06 mm with other experimental conditions unchanged using the SDS solution with a concentration of 0.1% and the coal sample with a roughness coefficient of 0.125.

Figure 11 indicates that the permeability coefficient of the coal sample with a fracture roughness of 0.125 is negatively correlated with the concentration of the SDS solution. This means that at an injection pressure of 0.3 MPa and a fracture aperture of 0.06 mm, the higher the concentration of the SDS solution, the greater the damage to the permeability coefficient of the coal sample with a roughness of 0.125.

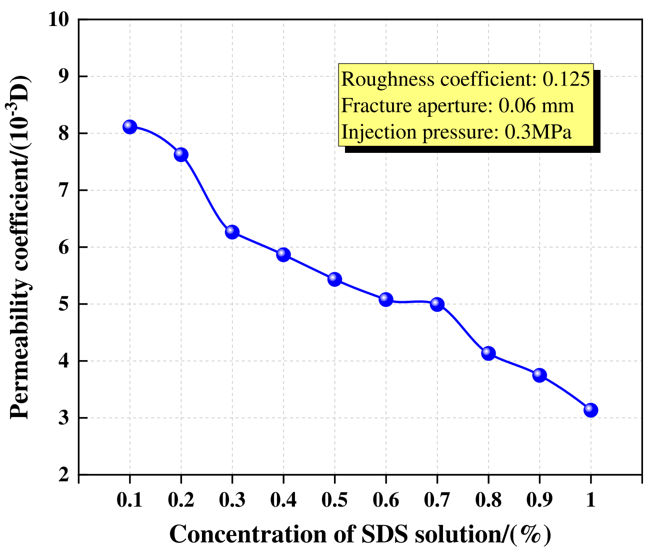

Figure 11. Influence of the concentration of the SDS solution on the permeability coefficient of the coal sample.

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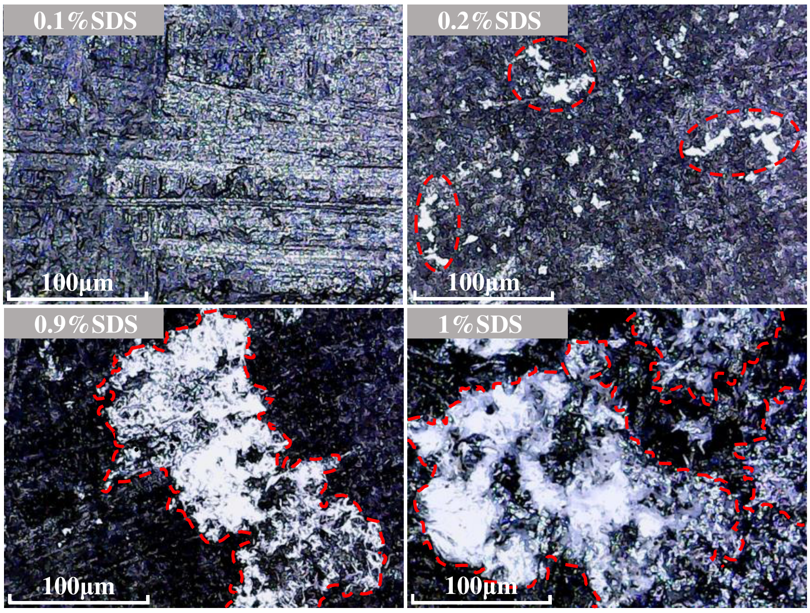

Figure 12. Microscopic observation of the SDS residue on the fracture surface.

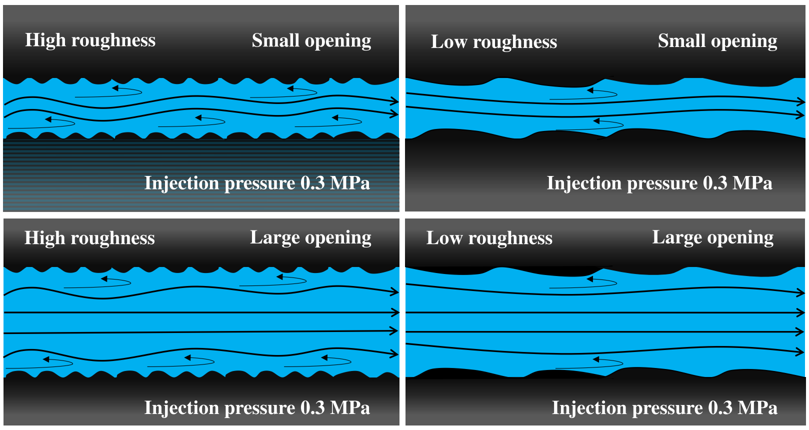

Figure 13. Mechanism of the influence of fracture roughness on the flow state of the solution seepage.

After the experiment, the coal sample was observed with a microscope, and the observation result is shown in Figure 12. The SDS surfactant solution with a concentration of 0.1% is adsorbed on the rough surface of the coal sample, and the SDS with a concentration of 0.2% begins to accumulate on the rough surface of the fracture. This phenomenon is positively correlated with the concentration of the SDS, which is also the reason for the obvious decrease in the residual permeability coefficient ratio after adding SDS. In addition, the downward trend of the residual permeability coefficient ratio is positively correlated with the concentration of the SDS.

The laboratory experiments aim to verify the influence of coal fracture surface roughness on seepage, and thus low injection pressure is set. According to the experimental results and the actual fact that adding an SDS surfactant in the coal seam water injection process is beneficial to coal seam water injection, it is inferred that because the SDS solution is adsorbed on the surface of coal fractures, the fracture channels are narrowed, and thus the permeability coefficient is reduced.

4. DISCUSSION

Through the observation using an ultra-depth-of-field 3D microscope, it is found that the rougher the coal fracture, the larger the irregular surface area of the fracture, and the longer the path that the solution flows through during the seepage process. This increases the frictional resistance that the solution needs to overcome during the seepage process. Previous researchers have pointed out that the size of the contact area also has a certain impact on the seepage process. Therefore, the greater the roughness of coal fractures, the smaller the permeability coefficient.

Owing to the influence of the surface roughness of coal fractures, the turbulence of seepage liquid occurs. The rougher the surface of coal fractures, the more obvious the turbulence. When the fracture aperture is large, compared with when the fracture aperture is small, the flow rate of distilled water increases more significantly with the increase in the injection pressure. The large flow rate overcomes the turbulence interference caused by the surface roughness of coal fractures and makes the distilled water move in a state of approximately laminar flow in the fractures of the four coal samples. This is why with the increase in the injection pressure, the effect of

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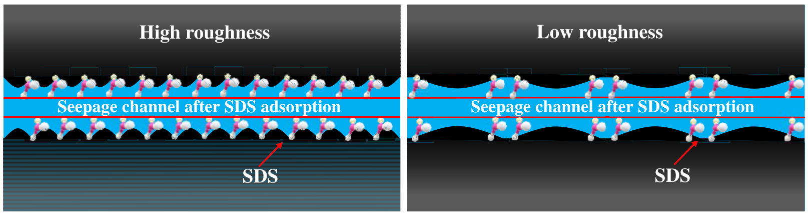

Figure 14. Mechanism of the effect of the SDS surfactant on seepage at different fracture roughnesses.

fracture surface roughness on seepage increases at a small fracture aperture and decreases at a large fracture aperture, as shown in Figure 13.

For a long time, it has been believed that surfactants can enhance the effect of coal seam water injection. However, it is indicated from this experimental study that an SDS surfactant also has an obstructive effect on seepage. When an SDS solution is used as the seepage fluid, the permeability coefficient of the coal sample is negatively correlated with the fracture surface roughness, while the residual permeability coefficient ratio of the SDS solution is positively correlated with the fracture surface roughness of the coal sample. As shown in Figure 14, this indicates that rough coal fractures are more likely to adsorb the SDS solution, resulting in narrowed fracture channels and a reduced permeability coefficient. Although the adsorption capacity of smooth coal fractures to the SDS solution is weaker than that of rough coal fractures, the surface morphologies of smooth fractures and rough fractures are changed after adsorption and tend to be similar. Therefore, the residual permeability coefficient ratio of smooth coal fractures is smaller than that of rough coal fractures. This is more obvious in the seepage experiment of the high concentration SDS solution. For the actual coal seam water injection process, this problem can be solved by increasing the temperature of the SDS solution to increase the solubility of SDS.

5. CONCLUSIONS

Through the seepage experiments of four coal samples with different fractures surface roughnesses, the influence of coal fracture surface roughness on seepage under different solutions was studied. The experimental results were analyzed and the following conclusions were drawn.

(1) When distilled water is used as the seepage fluid, the greater the surface roughness of coal fractures, the smaller the permeability coefficient. With the increase in the injection pressure, the effect of fracture surface roughness on seepage increases at the small fracture apertures of 0.06 and 0.12 mm, and weakens at the large opening of 0.18 mm. In the actual coal seam water injection process, the influence of the surface roughness of coal fractures on the water injection seepage process can be reduced by increasing the water injection pressure.

(2) With an SDS surfactant solution as the seepage fluid, the main factors affecting the seepage stage of coal seam water injection are injection pressure, SDS solution concentration, fracture aperture, and coal fracture roughness. Generally, the larger the fracture aperture, the higher the permeability coefficient. In addition, at the same fracture aperture and injection pressure, the permeability coefficient is negatively related to the concentration of the SDS solution for smooth coal fractures. At the same fracture aperture and the SDS solution concentration, the permeability coefficient is positively related to the injection pressure.

(3) The SDS surfactant solution can hinder the seepage stage of coal seam water injection, resulting in a decrease in the permeability coefficient. The main reason is that the SDS surfactant is adsorbed on the surface of coal fractures, resulting in narrowed fracture channels. This adsorption phenomenon is more obvious for coal samples with higher roughness coefficients.

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https://pubs.acs.org/10.1021/acsomega.2c04329

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This research was funded by the National Natural Science Foundation of China (Nos. 51974176, 52174194, 51934004), the Natural Science Outstanding Youth Foundation of Shandong Province (No. ZR2020JQ22), the Shandong Provincial Colleges and Universities Youth Innovation and Technology Support Program (No. 2019KJH006), the Taishan Scholars Project (TS20190935), and the National Natural Science Foundation of China (No. 52104200).

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https://doi.org/10.1021/acsomega.2c04329
ACS Omega 2022, 7, 32679−32689