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The Research on the Pressure Sensitivity for Low Permeability Fractured CBM Reservoir

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Abstract: In recent years, domestic CBM development has a certain scale with the further development of CBM mining technology. Due to the CBM reservoir has the characteristics of low permeability fractured and strong stress sensitivity, the reservoir damage is easily caused in the process of drilling. Therefore, it has practical significance to carry out the research on the pressure sensitivity for low permeability fractured CBM reservoir. Combined with the coal rock from the basin of Shanxi Qinshui, the experimental research on the pressure sensitivity was carried out under the condition of confining pressure and pore pressure, and analyzes the change law of permeability changing with the confining pressure and pore pressure, discusses the internal relations of pore pressure and fracture width, and thinks that increasing confining pressure and pore pressure will lead to coal fracture width decreases, cause the CBM reservoir permeability decreases, the conclusion has strong guiding significance for designing the drilling and completion plan and protecting the CBM reservoir.

Keywords: *confining pressure; pore pressure; permeability; fracture width*

1. Introduction

The CBM reservoir has the characteristics of low permeability fractured Generally, it must be hydraulic fractured to achieve the industrial value (Zhang Y., 2006), the natural fracture and cleat systems of CBM are very well, and its porosity, permeability and other physical parameters are very sensitive under the stress (Fatt I., et al, 1952, M Latchie A S., 1952, Wang L. Q.,et al, 2009, Zhang G. Y., et al,1995, Walsh J.B., 1981). In recent years, domestic CBM development has a certain scale with the further development of CBM mining technology. Because CBM reservoir is matrix pore-microfissure dual porosity media, permeability of coal rock is not only very low, but also affected greatly by pressure. During the evaluation for the reservoir damage, permeability is still an important index to low permeability fractured coal rock. Due to the low permeability of coal rock matrix, the intrusion of mud to the coal rock matrix is negligible normally, and the fracture is the main reservoir space and migrating channel, it should be taken into account in the evaluation of reservoir damage. The fracture width of coal and rock directly affects the amount of intrusion of drilling fluid to coal rock then affects the damage degree of drilling fluid to reservoir. Therefore, carrying out the research on the pressure sensitivity and influence of pore pressure on the permeability of low permeability fractured CBM reservoir, and analyzing the change law of fracture width has strong guiding significance for designing the drilling and completion plan and protecting the CBM reservoir.

2. Research on the stress sensitivity of low permeability fractured coal rock

Stress sensitivity reflects the response of rock pore geometry and morphology of fracture surface to stress change. A large number of field practice and indoor experiment study have shown that the stress sensitivity of CBM reservoir is very strong (Eric P. R., et al,2008, McKee C. R., et al,1988, Sun P. D.,2000),when stress damaged, even stress is reduced or removed , the permeability recovery value is smaller than initial value. Therefore, it has strong practical significance to study the stress damage law of CBM reservoir for the CBM productivity improvement.

2.1. Experimental process

(1) Select coal core with 3cm in diameter and 5cm in length, turn it to man-made fractured core by the method of split, dry coal core, measure the permeability of gas, then extract the fluid and make it saturation, measure its porosity.
(2) Set inlet pressure of 1MPa and confining pressure of 2MPa,using a standard brine water mass fraction of 1% as the experimental fluid, and measure liquid permeability of the coal core before the damage.
(3) Keep the inlet pressure is 0.5MPa invariant, increase confining pressure slowly, make net confining pressure of the coal core be 3.0MPa,

5.0MPa, 7.0MPa, 9.0MPa, 11.0MPa, 13MPa, 15MPa, 20MPa in turn.

(4) Measure the flow of liquid at each pressure point until the flow is stable.

(5) Reduce the confining pressure slowly; make the net confining pressure be 15MPa, 13MPa, 11MPa, 9.0MPa, 7.0MPa, 5.0MPa, 3.0MPa in turn.

(6) Keep every pressure point for 2h,then measure rock permeability, the experiment is over after all pressure points measured.

Table 1: *Physical parameters of coal core*

No.	Length (cm)	Diameter (cm)	Porosity (%)	Kg (10^{-3}μm^2)
QS1#	5.0	2.58	3.5	2.162
QS2#	5.0	2.52	8.1	3.025

Table 2: *Stress sensitivity experiment data under the net confining pressure*

NO.	Permeability (md)	Net confining pressure (MPa)							
		3.0	5.0	7.0	9.0	11.0	13.0	15.0	20
QS1#	Compression process	0.726	0.395	0.184	0.093	0.042	0.016	0.0062	0.0013
	Depressurization process	0.066	0.047	0.036	0.021	0.012	0.0049	0.0026	
QS2#	Compression process	4.127	3.151	1.293	0.784	0.492	0.171	0.045	0.019
	Depressurization process	1.269	0.618	0.191	0.098	0.061	0.045	0.020	

2.2. Experimental results

With the net confining pressure as horizontal coordinates and the permeability of coal rock as vertical coordinates, stress sensitivity curves of coal rock can be obtained as follows.

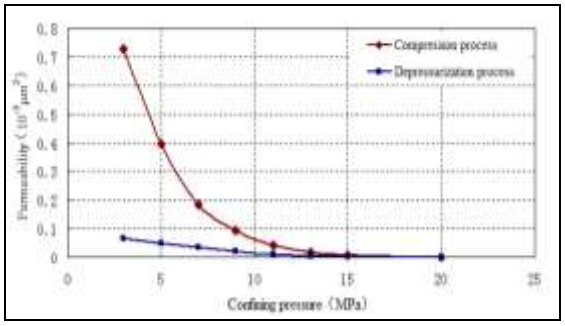

Fig1: *Stress sensitivity curve of QS1# coal rock*

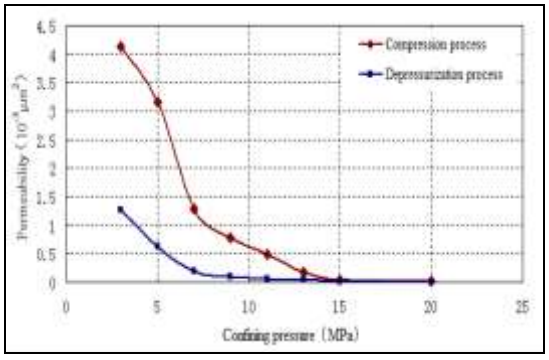

Fig2: *Stress sensitivity curve of QS2# coal rock*

2.3 Experimental analysis

From the experimental data and stress sensitivity curves, we can make the following analysis.

(1) As can be seen from the figure1 and figure 2, coal rock permeability reduces with the increasing of net confining pressure. Because of the increasing of net confining pressure, the effective stress of coal rock increases, then coal rock is compressed, so pores and fractures become small and microfracture closes, resulting in the decreasing of permeability.

(2) The permeability of QS1# and QS2# coal rock decreases more than 99% while the pressure increases from 2.5MPa to 20MPa, so the stress sensitivity of coal rock is very strong.

(3) With the increasing of net confining pressure, permeability first decreases rapidly, then decreases slowly, and tends to be stable finally. It shows that fracture closes quickly in the initial compression period, when the effective stress exceeds 11MPa, the trend of fracture closing slows down, and the permeability value is far less than the initial permeability.

(4) After the process of compression and depressurization, the permeability of coal rock cannot be restored, indicating that the permeability caused by stress is irreversible, and the coal rock is damaged permanently.

For the conventional sandstone with low permeability, permeability is exponential relationship with the pressure change. In order to study the relationship between permeability of coal rock and net confining pressure, with the net confining pressure as horizontal coordinates, the permeability of coal rock under compression as vertical coordinates, using fitting regression method by Excel, we can obtain the relationships between the permeability of coal rock and net confining pressure, which are shown in table 3, figure 3 and figure 4.

Table 3: *Permeability and net confining pressure fitting equation of coal rock*

No.	Fitting equation	Correlation coefficient (R^2)
QS1#	$y = 2.5985e^{-0.385x}$	0.9958
QS2#	$y = 14.705e^{-0.343x}$	0.9729

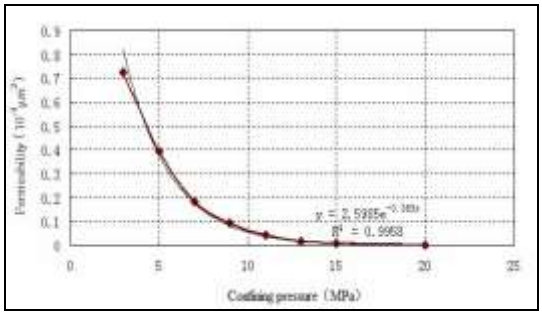

Fig3: *Fitting curve of QS1# coal rock between Permeability and net confining pressure*

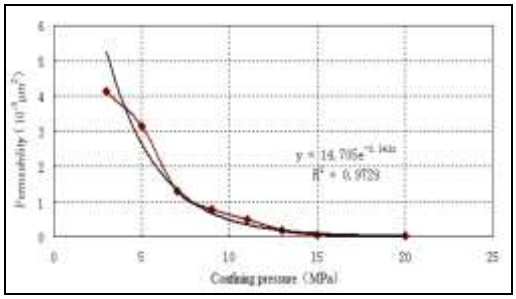

Fig4: *Fitting curve of QS2# coal rock between Permeability and net confining pressure*

Excel fitting results indicate that the relationship between the permeability and net confining pressure is very good to meet the exponential relationship, and the correlation coefficient is very high, which indicates that the fitting equation can well reflect the stress sensitivity of permeability.

3. Research on the Porepressure sensitivity of low permeability fractured coal rock

3.1. Effect of pore pressure on the permeability of low permeability fractured coal rock

CBM reservoir is matrix pore-microfissure dual porosity media, it is compressed by overburden pressure, which is related to the thickness and density of overlying rocks and it don't change with time. In the actual process of coal gas mining, the overburden pressure is constant, but pore pressure of CBM reservoir reduces progressively, so the effective pressure of CBM reservoir increases progressively.

In order to simulate the actual working condition, the experiment keeps the confining pressure constant in this experiment and measures the permeability of coal rock under variable pressure differences. First, set the pore pressure of 8MPa, then reduce the pressure differences continually, simulate the change of pore pressure of the reservoir in the CBM mining process. In this experiment, coal core outlet pressure is atmospheric pressure; the experimental results are shown in table4 and figure5.

Table 4*: pore pressure sensitivity experiment data of Coal rock*

Porepressure (MPa)	8.0	7.0	6.0	5.0	4.0	3.0
Permeability ($10^{-3}\mu m^2$)	0.052	0.041	0.036	0.028	0.024	0.018

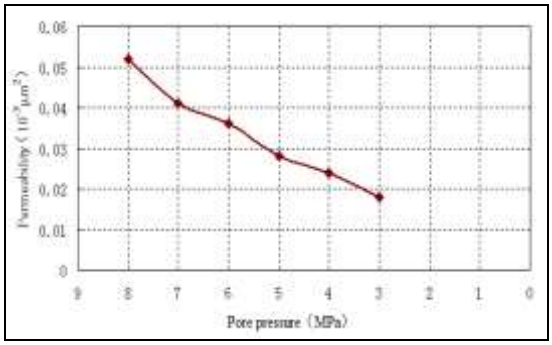

Fig5: *Pore pressure sensitivity curve of coal and rock*

As can be seen from the table4 and figure5, permeability of coal rock is reducing with the decrease of pore pressure. The permeability is $0.052\times10^{-3}\mu m^2$ when the pore pressure is 8MPa, and the permeability is only $0.018\times10^{-3}\mu m^2$ when the pore pressure is reduced to 3MPa.The permeability of coal rock is reduced by 65.38% only through the decompression process, It illustrates that reducing the pore pressure will cause the rise of total effective stress and the decrease of permeability of the coal rock under the condition of constant confining pressure.

3.2. Effect of fracture width on the permeability of low permeability fractured coal rock

Fracture is the main reservoir space and migrating channel of CBM for fractured reservoir. Based on the description of fracture shape and equivalent filtrational resistance principle, we can get the permeability of fracture reservoir.

$$K_f = \frac{lw^3}{12A} = 8.33\times10^6 \frac{Dw^3}{A} \qquad (1)$$

The parameter declaration: w means fracture width in cm; D means coal rock diameter in cm; A means cross-sectional area of coal rock in cm^2; K_f means fracture permeability, μm^2。 From the equation (1), we can see that permeability of fractured rock is mainly affected by

the fracture width, and the permeability of the coal rock changes large with the opening and closing of micro-fractures, it can be concluded that the permeability goes down when the micro-fractures tends to be closed due to the increase of effective stress, and it goes up again when the closed micro-fractures recover slowly with the effective stress reduction.

In this experiment, the variation of permeability and fracture width with time changes is tested in the compression process. By keeping the confining pressure unchanged, and setting different test pressure, the flow of liquid through the coal rock at different time can be measured, and the permeability of coal rock can be calculated, the fracture width of coal rock at different time can be calculated by the equation (1), and the experimental results are show in the table5 and table6.

Table5: *experimental data of permeability and fracture width with the test time changes under the pressure difference of 2 MPa*

Test time (min)	Permeability ($10^{-3}\mu m^2$)	Fracture width (μm)
10	0.036	2.061
20	0.031	1.961
30	0.027	1.872
40	0.026	1.849
50	0.024	1.800
60	0.022	1.749
70	0.021	1.722
80	0.019	1.665
90	0.016	1.573
100	0.015	1.539
110	0.012	1.429
120	0.012	1.429

Table6: *Experimental data of permeability and fracture width with the test time changes under the pressure difference of 1 MPa*

Test time (min)	Permeability ($10^{-3}\mu m^2$)	Fracture width (μm)
10	0.045	2.220
20	0.041	2.152
30	0.037	2.079
40	0.035	2.042
50	0.032	1.981
60	0.027	1.872
70	0.026	1.849
80	0.024	1.800
90	0.022	1.749
100	0.021	1.722
110	0.020	1.694
120	0.020	1.694

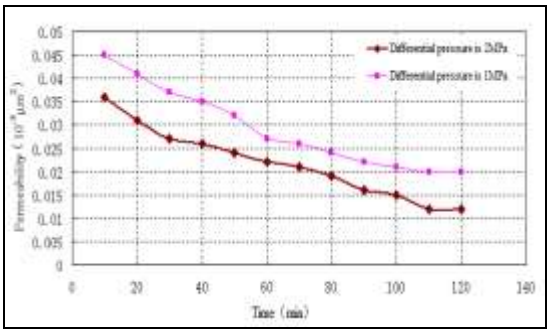

Fig6: *Permeability curve with the test time changes under the different test pressure*

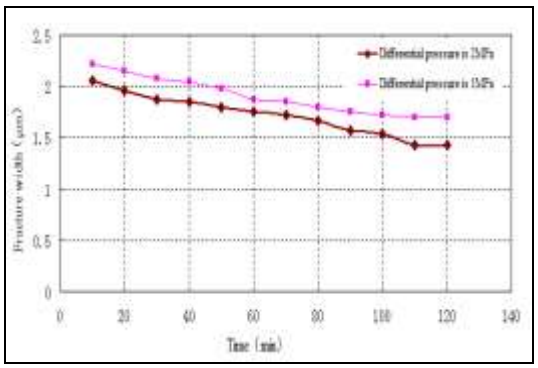

Fig7: *Fracture width curve with the test time changes under the different test pressure*

Figure 6 and figure 7 curves reflect the change law of permeability and fracture width of coal rock with the test time under different test pressure. As can be seen from the curve in figure6, the permeability of coal rock reached to the maximum value in the initial stage of experiment, the permeability decreased and finally tended to be stable gradually with the increase of time. The trend of curves obtained is the same under different test pressure. As can be seen from figure6 and figure 7, the trend of permeability and fracture width of coal rock with the test of time is the same; it verifies that the permeability of coal rock is mainly affected by the fracture width furtherly.

4. Conclusion

(1) The stress sensitivity of coal rock is very strong. The permeability of coal rock decreases rapidly with the increase of stress, and the permeability caused by stress is irreversible, even coal rock stress is back to the initial state, the permeability recovery value is smaller than initial value, and the coal rock is permanently damaged.

(2) With the gradual exploitation of CBM, reducing the pore pressure will cause the rise of total effective stress, so pores and fissures become small and microfracture closes, resulting in the decrease of permeability.

(3) CBM reservoir is matrix pore-microfissure dual porosity media, permeability of fractured rock is mainly affected by the fracture width. CBM reservoir protection measures should be taken in the process of drilling in order to prevent the fracture closure and reduce reservoir damage.

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