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Experimental study on conductivity of hydraulic fracture in coal bed

Hydraulic fracturing is an important stimulation technology of coal bed methane well. It is different between CBM reservoirs and conventional oil and gas reservoirs. The research conclusion of coal bed hydraulic fracture conductivity is different from that of conventional oil and gas reservoir. It is necessary to carry out the research of coal bed hydraulic fracture conductivity. In this paper, fracture conductivity of coal rock is evaluated by FCES-100 fracture conductometer. The effect of closure pressure, sand concentration, time, the natural fractures of coal rock as well as proppant type on fracture conductivity are studied. The study shows that as the closure pressure increases, there is a decline of more than 50% about coal bed fracture conductivity. The conductivity under high sand concentration is significantly higher than that under single layer sand concentration. Thereby, increasing the concentration of sand is conducive to the formation of high conductivity fracture. With the time increase, fracture conductivity is decreased with a decline of 20%~35%. Natural fracture has a direct impact on conductivity, and this impact is performed particularly evidently in the case of a higher closure pressure. Meanwhile proppant type is also an important factor in affecting the fracture conductivity.

Keywords: *Coal bed; hydraulic fracture; proppant; conductivity.*

Introduction

Hydraulic fracture is commonly used as an oil stimulation measure. The purpose of hydraulic fracture is to generate a high-conductivity fracture to wellbore, so that the fluid in reservoir can flow into wellbore with less resistance. Since hydraulic fracture conductivity is a key factor in affecting productivity, it is necessary to carry out an evaluation on it. However, the CBM reservoirs differ greatly from conventional oil and gas reservoirs. CBM reservoirs are featured by less burial depths, low permeability, relatively low pressure, low Young's modulus, high Poisson's ratio and lower hardness [1,2,3]. The study results of conventional oil and gas reservoirs hydraulic fracture conductivity cannot be applied to study on coal bed [4]. Therefore there is the need for a specialized study on conductivity of coal bed hydraulic fracture. According to previous studies, fracture conductivity is usually related to reservoir properties, closure pressure, proppant properties, proppant concentration and fracturing fluid [5,6,7,8,9,10]. This research focuses on an experimental evaluation on conductivity of coal bed hydraulic fracture based on its characteristics.

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1. Experimental principles and equipment

In this experiment, FCES-100 Fracture Flow Conductometer is employed, which is made by American company Core-Lab. It can withstand 150°C test temperature and 200MPa closure pressure to the maximum extent. The apparatus is designed in accordance with API standard and conducted in standardized API conductivity cell (Fig.1). The experiment strictly follows API standardized processes. With reference to Darcy's Law, proppant pack permeability and conductivity formula is shown as follows:

(1) Proppant pack permeability:

$$k = \frac{5.411 \times 10^{-4} \mu Q}{\Delta p W_f} \qquad \text{... (1)}$$

(2) Conductivity of proppant pack:

$$kW_f = \frac{5.411 \times 10^{-4} \mu Q}{\Delta p} \qquad \text{... (2)}$$

where k - fracture permeability (μm^2), Q - rate of flow in fracture (cm^3/min), μ - fluid viscosity (mPa·s), Δp - pressure difference of two ends (kPa), W_f - fracture width (cm). The conductivity can be calculated based on pressure difference and rate of flow.

2. Core sample preparation

The coal sample is gained by processing coal brick. The processed coal sample is 17.8 cm long, 3.8 cm wide and 1-2 cm thick with semicircular end (Fig.2).

3. Conductivity cell making

After coal sample is prepared, it can be used to make conductivity cell with conductivity trench. Due to the

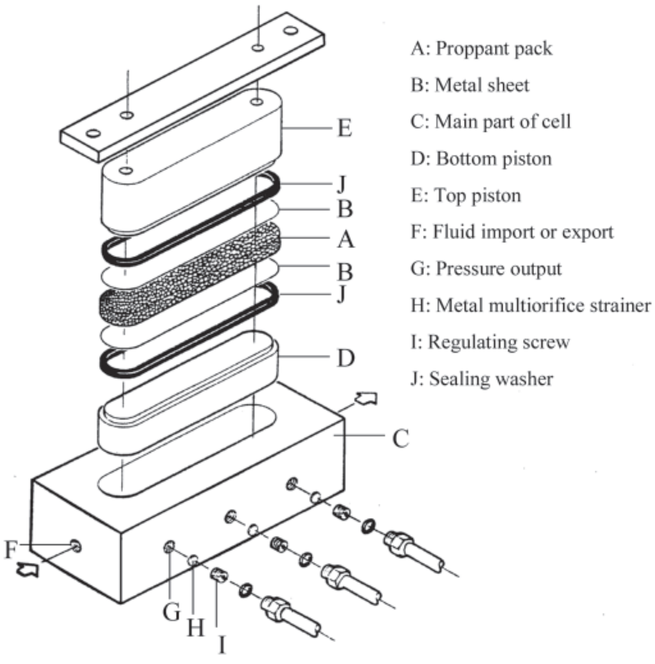

Fig.1 Proppant conductivity cell

Fig.2 Processed coal sample

inevitable gap between coal sample to be processed and conductivity cell inner parts, conductivity would be affected. This experiment adopts a kind of thermostable gel to get rid of its effect. When spreading the gel on the sides of coal sample, the gel would become a kind of solid gel similar to rubber. After putting coal sample coated with gel into conductivity cell and laying down quartz sand of certain concentration, the conductivity cell is made and sealed.

4. Experimental scheme

In conductivity cell, proppant pack stuck between two coal samples serves as simulated coal bed fracture. The fluid will flow through the proppant pack at stable rate. By adjusting closure pressure, pressure time and proppant concentration, a curve can be drawn which shows how fracture conductivity change with affect of these factors. Experimental results are derived through analysis on different characteristics of the curve.

This experiment takes quartz sand of 20-40 mesh and ceramisite of 20-40 mesh as proppant. Ten tests are carried out for conductivity under circumstances of high proppant concentration and single layer proppant concentration. Six pressure points are chosen to be tested for 12 hours (short-term), 48 hours (long-term) and 24 hours (comparative tests for conductivity of different proppants). For the convenience of operation and well-distribution of proppant, this experiment chooses single layer proppant concentration of $2kg/m^2$. As for all the ten tests, six of them employ quartz sand clamped by coal sample, two of them by sandstone sample and the other two adopt quartz sand and ceramisite clamped by steel plate respectively. The experiment scheme can be seen in Table 1.

5. Results analysis

5.1 Effect of closure pressure on conductivity

Closure pressure comes into being when fracture closes and it is passed to proppant by strata. The force of closure pressure gives rise to proppant crushing, so that the proppant particles are reduced in size and in the degree of sphericity, while the area increases and the particle diameter becomes uneven. Closed pressure will further compact the proppant pack, which makes porosity smaller and proppant can be embedded in the strata with decrease of fracture width. All these factors will lower the permeability of proppant pack.

As shown in Fig.3, the conductivity of coal sample No.1 and No.2, and sandstone sample decreases obviously with gradual increasing of closure pressure. As the closure

Table 1: Experimental scheme

Closure pressure	Proppant concentration: 10 kg/m^2					Proppant concentration: 2 kg/m^2			Proppant concentration: 5 kg/m^2	
	Quartz sand					Quartz sand			Quartz sand	Ceramisite
	1 Coal sample	2 Coal sample	3 Coal sample	4 Coal sample	1 Sandstone sample	5 Coal sample	6 Coal sample	2 Sandstone sample	Steel plate	Steel plate
4 MPa	12 h	12 h			12 h	12 h	12 h	12 h		
8 MPa	12 h	12 h	48 h	48 h	12 h	12 h	12 h	12 h		
12 MPa	12 h	12 h			12 h	12 h	12 h	12 h		
16 MPa	12 h	12 h			12 h	12 h	12 h	12 h		
20 MPa	12 h	12 h	48 h	48 h	12 h	12 h	12 h	12 h		
24 MPa	12 h	12 h			12 h	12 h	12 h	12 h	24 h	24 h

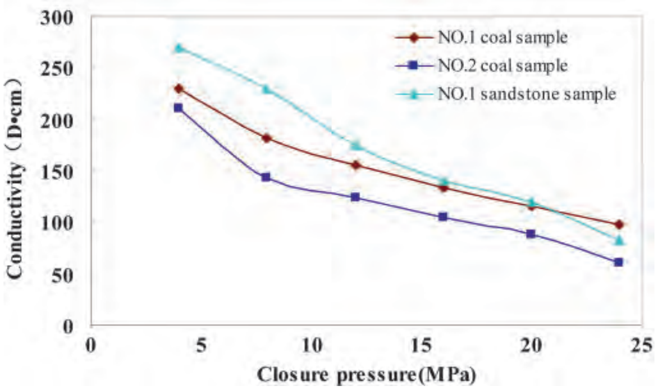

Fig.3 Dependence of fracture conductivity on closure pressure

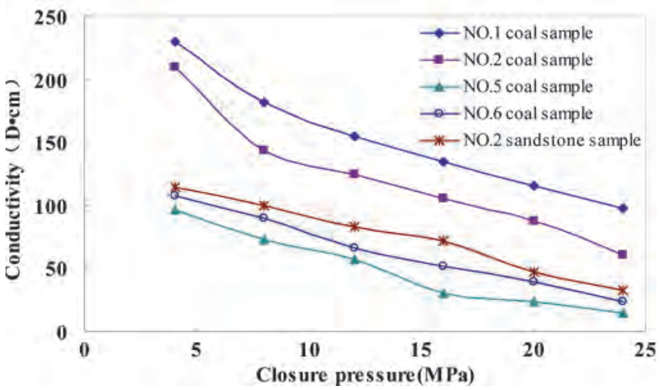

Fig.4 Dependence of fracture conductivity on proppant concentration

pressure rises from 4 MPa to 24 MPa, the fracture conductivity of coal sample No.1 declines by 58.7%, while the coal sample No.2 71.4% and sandstone 69.6%. When the closure pressure is lower than 21.5 MPa, conductivity of sandstone No.1 is always greater than that of coal sample. This may be caused by the fact that coal sample is less harder than sandstone sample. With closure pressure increasing, proppant embedment occurs, reducing fracture conductivity. Thereby closure pressure exerts notable influence on conductivity of hydraulic fracture in coal bed.

5.2 Effect of proppant concentration on conductivity

As seen in Fig.4, based on conductivity comparison of coal sample in single layer proppant concentration and the other two tests in high proppant concentration of 10 kg/m^2, under the same closure pressure, it is obvious that the conductivity of 20-40 mesh sandstone in high proppant concentration is higher than that in single layer proppant concentration, with maximum difference reaching 134 Docm. Fig.4 shows that when it is in single layer proppant concentration, the conductivity of coal sample No.5 and No.6 continuously decreases from 100 Docm under 4 Mpa to 20 Docm while closure pressure is 24 Mpa. It shows that increasing the proppant concentration makes it possible to form fracture with high conductivity. It is also observed that the conductivity of coal sample No.5 and No.6 is lower than that of sandstone No.2 in single layer proppant concentration. This reflects that the embedding reduces conductivity.

5.3 Effect of time on conductivity

Figs.5 and 6 are reflection of fracture conductivity changes with time under closure pressure of 8 MPa and 20 MPa respectively. Fracture conductivity gradually descends as time goes by. The decline is more rapid at early stage and slows down gradually later. Under closure pressure of 8 MPa for 48 hours, conductivity of coal sample No.3 declines by 20% and No.4 by 22.3%; under that of 20 MPa for 48 hours, No.3 falls by 20%, while No.4 by 34.4%. At later stage of experiment, the conductivity does not seem to be stable, but still takes on slight decline.

5.4 Effect of coal bed natural fracture on conductivity

It is noted in Fig.3 that on same conditions, conductivity of coal sample No.1 and No.2 show great difference, with the gap even reaching some 39 Docm. The conductivity of coal sample No.1 is proved even higher than that of sandstone sample after closure pressure exceeds 21.5 MPa. The comparison of two coal samples reveals that coal sample No.1 has many cleats and fissures, including a visible natural fracture along the flow

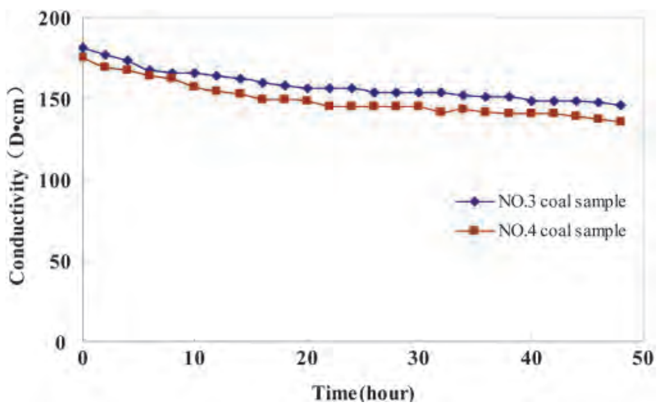

Fig.5 Dependence of fracture conductivity on time under closure pressure of 8 MPa

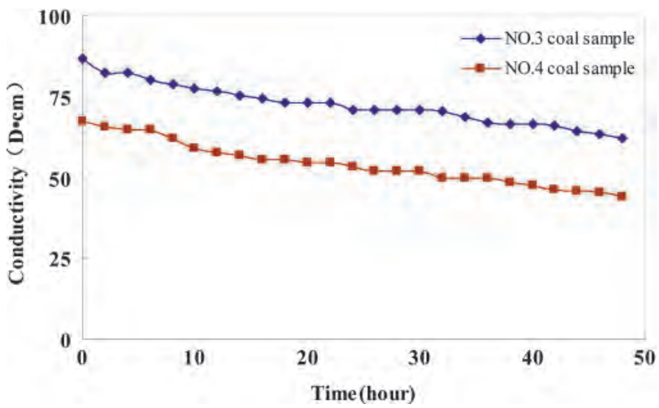

Fig.6 Dependence of fracture conductivity on time under closure pressure of 20 MPa

direction. However, the coal sample No.2 is relatively more complete and uniform with less cleats and fissures. From Figs.5 and 6, differences exist in conductivity of coal sample No.3 and No.4, especially under high closure pressure. It is the coal sample No.3 that notably has higher conductivity than coal sample No.4. With comparative analysis, there are two natural fractures along flow direction existing in coal sample No. 3, intersecting in a certain angle. According to this experiment results, existence of natural fractures and cleats has great influence on conductivity, especially on the condition of high closure pressure.

5.5 Effect of proppant type on conductivity

Fig.7 is the test results for how the conductivity of 20-40mesh quartz sand and ceramisite proppant pack both clamped by steel plate change with time. The test lasts for 24 hours. As seen in this figure, due to high strength of ceramisite, its conductivity is obviously higher than that quartz sand's. Therefore, the choice for proppant with high strength makes it possible to form high-conductive fracture. Fig.7 also shows that the conductivity of the two decline evidently during the early 8 hours. This feature is similar to the result of tests for coal sample No.3 and No.4. However, in this test, the conductivity sees nearly no decrease during the later stage, while conductivity of coal sample No.3 and No.4 keep dropping during the whole 48-hour course of experiment. As stated below, embedment of proppant into coal sample and coal dust produced by friction with coal sample finally causes the slight lowering of conductivity.

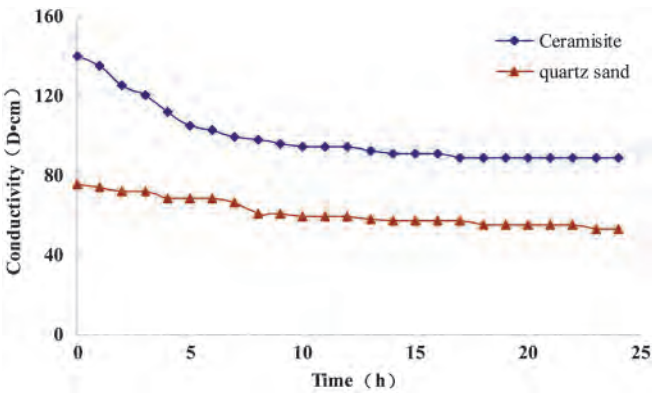

Fig.7 Fracture conductivity of quartz sand and ceramisite proppant under closure pressure of 24 MPa

6. Conclusions

(1) Closure pressure exerts notable influence on conductivity. When the closure pressure goes up to 24 MPa from 4MPa, the conductivity of all coal sample and stone plate reduces by about 50%.

(2) Fracture conductivity is very sensitive to proppant concentration. The conductivity in single layer proppant concentration is far lower than that in high proppant concentration, which is easier to form fracture with high-conductivity.

(3) Time is also one of the major influencing factors. Fracture conductivity gradually decreases as closure pressure lasts. The conductivity falls fast during the early stage and gradually slows down. After 48 hours of test, fracture conductivity of coal sample usually drops by 20% to 35%.

(4) Natural fractures in coal bed play a positive role in improving conductivity, especially under high closure pressure.

(5) Proppant with high strength has a beneficial effect on forming high-conductive fractures.

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