Study on fault sealing mechanism based on rock physics simulation experiment

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Abstract. At present, the development of fault oil and gas reservoirs has become an important way for to increase oil and gas productivity in China. However, due to the complex internal stress state of rock faults, the phenomenon of oil and gas escape is prone to occur during the mining process, so it is of great significance to study the sealing mechanism of the rock fault. For this reason, based on the theory of fault sealing, rock physical simulation experiments of fault sealing were carried out, and the mechanism of fault sealing and its main controlling factors were deeply studied. The results show that the rock fault dip and the argillaceous content of the fault filling are the main controlling factors for fault sealing; The essence of fault lateral sealing and vertical sealing is the sealing of the displacement pressure difference; As the dip angle of the fault increases, the lateral sealing of the fault becomes better, while the vertical sealing becomes worse; with the increase of the argillaceous content of the fault filling, the lateral and vertical sealability of the fault becomes better.

1. Introduction
Faulted oil and gas reservoirs are widely distributed in China. However, the internal stress of the fault zone is complex, and it is easy to cause oil and gas to escape during the mining process. Therefore, the study of fault sealing mechanism is of great significance to the exploration and development of faulted oil and gas reservoirs. Many scholars have carried out relevant research on this. Yielding[1] analyzed the reasons for fault sealing from the perspective of lithology, and proposed the concepts of fault gouge ratio SGR and smear factor; Clarke[2] used three-dimensional analysis technology for the first time to obtain the SGR distribution map of the fault gouge ratio; Vivek[3] proposed a method of artificially injecting CO2 into the fault to seal the fault through precipitation. Zhou Xingui[4] found that the greater the angle of intersection between the current horizontal principal compressive stress direction and the fault strike, the greater the possibility of the fault blocking oil and gas; Li Qiang[5] combined fault sealability with oil and gas accumulation, and used the orthogonal test design method to determine the factors affecting the displacement pressure of the fault rock. The higher the SGR value, the better the lateral sealing of the fault. The above-mentioned research is mainly aimed at theoretical research on fault sealing, and physical simulation experiments are rarely used to study fault
sealing mechanism. Therefore, this paper takes the 4th block of Zhunzhong as the research area, analyzes the mechanism of fault sealing through experiments, and deeply researches the influencing factors of fault sealing.

2. Physical simulation experiment of fault sealing
The essence of fault sealing is the difference in permeability. Through physical simulation experiments to create an ideal experimental environment, restore the true situation of the fault.

2.1. Experimental sample
The rock samples of the fault closure physical model experiment are taken from the Qigu Formation in a well area of Block 4 in Zhunzhong, the depth range is 4454.42~4468.3m, and the core size is Φ25×65mm.

2.2. Experimental program
Set up the two variables of fault dip and argillaceous content of the fault filling to carry out the experimental study of the fault sealing, ignoring other secondary influencing factors.

(1) Experiment on the influence of fault dip on fault lateral sealing
   Set up fault physical models at different inclination angles. The argillaceous content of the fracture filling is 50%. It is assumed that the confining pressure corresponding to the conventional permeability during the pressurization process is the critical closing pressure. Taking the fracture surface as a single fracture as an example, the core is cross-sectioned at different angles α, and five groups of models are set to α1=30°, α2=45°, α3=60°, α4=75°, α5=90° respectively. The cutting direction is shown in figure 1.

(2) Experiment on the influence of fault dip on fault vertical sealing
   As shown in figure 2, the full-diameter core is cut along the vertical direction, which is similar to the lateral closed model. The cut angles are set to β1=0°, β2=5°, β3=10°, β4=15°, β5=20°. (Corresponding to the fault dip in the actual formation is 90°, 85°, 80°, 75°, 70°)

   Figure 1. Schematic diagram of lateral closed physical model.  
   Figure 2. Schematic diagram of vertical closed physical model.

(3) Experiment on the influence of argillaceous content of the filling material in the fault zone on fault lateral sealing
   Considering actual reservoir conditions, physical models of 45° dip angle faults with argillaceous content of 30%, 40%, 50%, 60%, and 70% are set.

(4) Experiment on the influence of argillaceous content of the filling material in the fault zone on fault vertical sealing
   Considering the actual geological conditions, physical models of 80° dip angle faults with argillaceous content of 30%, 40%, 50%, 60%, and 70% are set.

3. Analysis of results

3.1. Experimental analysis of the effect of fault dip angle on fault lateral sealing
   According to the experimental results, the relationship curve between the confining pressure and the permeability of the fault lateral sealing model is established as shown in the figure below.
It can be seen from figure 3 to figure 7 that the permeability of the fault lateral sealing model is much higher than that of the conventional core. Under the same geological conditions, the ability of the fault to transport oil and gas increases.

It can be seen from figure 8 that as the fault dip increases, the critical closure pressure decreases. In the actual formation, the greater the dip angle of the fault, the better the lateral sealing ability of the fault.

3.2. Analysis of the Experimental Results of the Influence of Fault Dip Angle on fault vertical sealing

According to the experimental results, the relationship curve between the confining pressure and the permeability of the fault vertical sealing model is established as shown in the figure below.
It can be seen from figure 9 to figure 13 that the vertical rock permeability of the fault is much greater than the conventional permeability of the rock sample, and the permeability of the fault vertical closure model is approximately 12~15 times that of the conventional permeability.

It can be seen from figure 14 that as the dip angle increases, the critical closure pressure of the vertical sealing of the fault gradually increases, its sealing performance becomes worse, and the effective stress preventing the vertical migration of oil and gas becomes larger.

3.3. The experimental results of the influence of argillaceous content on fault lateral sealing

According to the experimental results, the relationship curve between the confining pressure and the permeability of the fault lateral sealing model is established as shown in the figure below.

It can be seen from figure 15 to figure 19 that with the increase of the argillaceous content of the fracture filling, the rock permeability gradually decreases under the same confining pressure. The higher the argillaceous content of the fracture filling, the better the lateral sealing of the fault, and vice versa, the worse the lateral sealing of the fault.

It can be seen from figure 20 that as the argillaceous content increases, the critical closure pressure of the fault lateral closure model gradually decreases, and the critical closure pressure ranges from 12.86 to 20.58 MPa.
3.4. The experimental results of the influence of argillaceous content on fault vertical sealing

According to the experimental results, the relationship curve between the confining pressure and the permeability of the fault vertical sealing model is established as shown in the figure below.

![Figure 21. Vertical 30%](image1)

![Figure 22. Vertical 40%](image2)

![Figure 23. Vertical 50%](image3)

![Figure 24. Vertical 60%](image4)

![Figure 25. Vertical 30%](image5)

![Figure 26. Critical closure pressure curve of vertical argillaceous content.](image6)

It can be seen from figure 21 to figure 25 that with the increase of the model argillaceous content, the permeability of the rock decreases under the same confining pressure. In the actual formation, the higher the argillaceous content of the fault filling, the better the vertical sealing of the fault.

It can be seen from figure 26 that as the argillaceous content increases, the critical closure pressure gradually decreases. In fractures with high argillaceous content, only a small confining pressure is needed to achieve the vertical sealing requirements and prevent the migration of oil and gas.

4. Fault Sealing Mechanism

4.1. Fault lateral sealing mechanism

The experimental results of the lateral sealing of the fault are summarized as follows:

![Figure 27. Lateral closed dip-permeability curve.](image7)

![Figure 28. Lateral closed argillaceous content-permeability curve.](image8)
It can be seen from figure 27 and figure 28 that as the fracture filling argillaceous content increases, the rock permeability gradually decreases. The higher the argillaceous content, the lower the fracture porosity and the smaller the pore radius. Therefore, the higher the drainage pressure of the fault, the higher the oil and gas sealing height; The essence of the lateral sealing effect of the fault is the sealing of the displacement pressure difference.

4.2. Fault vertical sealing mechanism

The experimental results of the vertical sealing of the fault are summarized as follows:

![Figure 29. Vertical closed dip-permeability curve.](image)

![Figure 30. Vertical closed argillaceous content-permeability curve.](image)

It can be seen from figure 29 and figure 30 that under the same confining pressure, as the argillaceous content increases, the rock permeability gradually decreases, the essence of fault sealing is the sealing of the displacement pressure difference. However, the argillaceous content required for vertical sealing is higher than for lateral sealing.

5. Conclusion

The conclusions of this research are as follows:

1) As the dip angle of the fault increases, the lateral sealing of the fault becomes better; the vertical sealing becomes worse.

2) As the argillaceous content of the fault filling increases, the better the lateral sealing of the fault, and the better the vertical sealing of the fault; In the actual formation, the higher the argillaceous content of the fracture filling, the better the sealing of the fault.

3) The dip angle of the fault and the argillaceous content of the fault filling are the main controlling factors for the sealability of the fault. The essence of the fault seal is the seal of the displacement pressure difference.

The results of the research have guiding significance for the exploration and development of faulted oil and gas reservoirs, aiming to improve the efficiency of oil and gas exploration and development.

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