

Experimental study on critical closing pressure of mudstone fractured reservoirs

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Abstract: In the process of oil and gas exploitation of mudstone-fractured reservoir in Daqing oilfield, the permeability of fracture is easily affected by the influence of stress change, which is shown by the sensitivity of the permeability to the stress. With the extension of time mining in the fractured mudstone reservoir, fracture stress sensitivity is obvious in vast decline of production and great influence on reduced yields. In order to reasonably determine the way of developing method, working system and the exploitation rate of the reservoir, correspondingly protecting reservoir productivity, improve ultimate recovery. On the basis of the previous research on the stress sensitivity of fractured mudstone, this essay studied the critical closing pressure of the simulated underground fractured mudstone under the laboratory condition.

Keywords: Mudstone; fractured reservoir; critical pressure; closure pressure

The fractured mudstone in the change of the stress will have deformation causing the closure, reducing the formation permeability and the production of oil and gas wells, fractured mudstone is influenced by the change of stress, the most influential parameter is the formation permeability, if we make permeability as the characterization parameter of the degree of mudstone fracture closure, then the quantify to what specific value could to be able to distinguish the closure size of the stress under this value, the key of the study is how to quantify the change of the stress in the crack closure and the selection of the appropriate characterization of the parameters, this is the problem we have to solve in the research, adopts critical closing pressure method to study fractured mudstone reservoirs in this paper.

I. EXPERIMENTAL PRINCIPLE

The internal structure of the rock can be abstracted as a dense non-porous and fractured bedrock skeleton part and able to store the fluid pore and fracture space portion (Fig.1). The storage space of sandstone is mainly composed of pores which are differ in size, the ratio of pore volume and the volume of rock is called the porosity of rock, showing the ability of the rock to storage fluid; the mudstone is composed of very fine components in microscopic scales, the physical properties of rock is quite dense, and the porosity is very low, due to the stress from underground, the internal structure of rock deformed into crack and become the storage space of mudstone, theoretically equivalent to the pores of the sandstones.

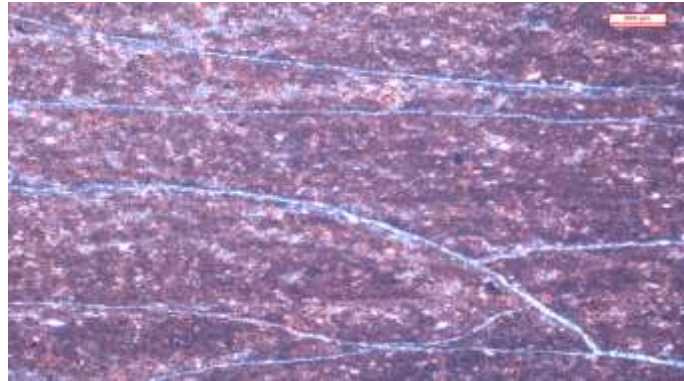


Fig.1 The microscopic picture of zonal distribution in the fractured core

Normally, external pressure, internal pressure of rock force on the rock skeleton stress to maintain a balance, when external pressure increases and internal pressure decreases, With the increase of the pressure difference, the space is gradually reduced, and the rock volume is close to the bedrock volume. The porosity and permeability of the rock are close to the porosity and permeability of the bedrock. At that time the fracture of mudstone is considered closure, the corresponding pressure is called the critical closing pressure. The permeability is called the critical permeability. This critical value can be used to characterize the degree of closure of the mudstone fracture.

In the laboratory we firstly recorded the permeability of the mudstone without cracks under no force, as the critical permeability (close to bedrock); then we used artificial joint to the mudstone core samples to simulate fractured mudstone characteristics underground, applying external stress to those core samples contained fractures and record the value of permeability when stress changed. When the stress increased making the permeability gradually decreased to approach the rock permeability, recorded pressure value at the time, this pressure value is called the crack critical closure pressure of the tested core samples, if it's higher this the pressure, mudstone fracture closure; if it's below the pressure, the mudstone fractures open.

II. EXPERIMENTAL PROCEDURE

In the experiment, the FYKS-2 type high temperature overburden pressure porosity and permeability tester was used to change the external pressure and internal pressure, measuring the porosity and permeability of the core samples, the principle and procedure are:

- (1) Retrieving the original core through drilling, cutting, grinding and other processes to make core samples which meet the experimental specifications while numbering them to show distinction. In the process of making core samples, as the characteristics of the brittle mudstone, the processing of the qualified rate is relatively low, resulting in the little experimental samples and high cost;
- (2) Manually fracturing to some core samples by the external stress and get the fractured mudstone core samples;
- (3) Using the FYKS-2 type high temperature overburden pressure porosity and permeability tester to test and record the data the permeability of the unfractured cores;
- (4) Using the FYKS-2 type high temperature overburden pressure porosity and permeability tester to test and record the permeability of fractured rock samples;
- (5) Analysis of experimental results.

III. THE RESULT OF THE EXPERIMENT

We put the mudstone core samples before and after the pressure joint on high pressure hole penetration tester measuring the porosity and permeability the which were pressed, we recorded the experimental data and carried the contrast. The mudstone fracture caused by artificial fractured effectively changed the porosity of mudstone core samples, showing an obvious difference before and after the pressure joint, before the pressure joint the porosity of mudstone is relatively small, while the situation is completely opposite after the pressure joint. This result indicates that (1) porosity is very low in the mudstone without fractures; (2) The effective porosity of mudstone reservoir mainly from to the fracture, that is to say the main reserve space of the mudstone reservoir is the cracks forming in the mudstone due to the stress changes in the historical years.

From the permeability contrast before and after of the pressure joint we can be see (Fig.2):

(1) The change extent of permeability is varied before and after the pressure joint in different cores, it is the phenomenon which is resulted from the artificial fracture, the experimental sample formed natural fractures in the underground complex geological environment through a long geological history, it is difficult to accurately simulate the process of artificial joint in the laboratory.

(2) The external pressure-permeability variation trend is roughly an exponential relationship, the external pressure-permeability which measured by high pressure permeability experiment not only includes the value when the stress loading but also contains the value when unloading stress, if we put two groups of experiment data to scattered chart, we could notice the permeability of the unloading process is lower than that in the loading process, the reason to this is in the process of loading stress, mudstone fracture occurred plastic deformation, when the stress unloading it cannot restore the original shape, leading to the decrease of permeability.

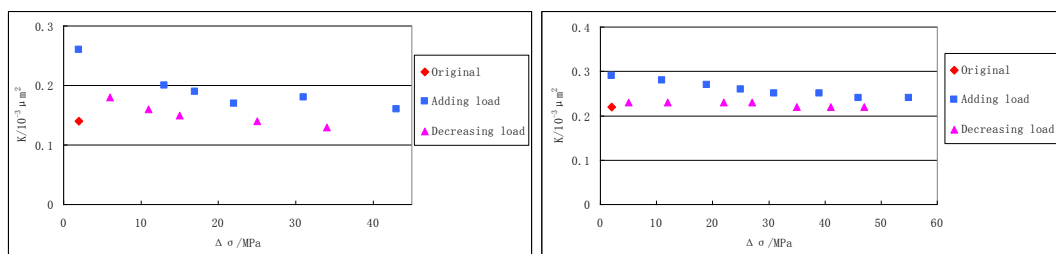


Fig.2 Permeability contrast chart before and after forming fissure

IV. THE RESULT ANALYSIS

Those mudstone samples which have not been pressure-joint, their permeability is bedrock permeability, after pressure joint the permeability will be greater than the permeability before due to the presence of cracks, as the increasing of external pressure, the mudstone fracture is gradually closed by stress, following the decreasing of the permeability, when the penetration rate approaching the sample permeability before pressure joint, the mudstone fracture could be considered as closure, we call the external point pressure values as the critical closing pressure.

As we can see from Fig.2, the value of the point of penetration in the curve is seen before pressuring from the curve, if the number is over this value, we could know that the cracks have been closed. If the pressure range has not yet reach the critical closing pressure point, we could know that the fracture of the mudstone is still not closed.

The external pressure sensitive curve from the lab calculated shows the stress sensitivity of rock by the increase of external and the decrease of the internal pressure. In view of the actual situation of the field, it need to convert the external pressure sensitive curve to the internal pressure sensitive curve in order to calculate the critical closing pressure.

The stress sensitivity equation under any pressure difference is:

$$\begin{cases} k_i = k_0 e^{-b(\sigma - \phi p_i)} \\ k = k_i e^{-b\phi \Delta p} \end{cases} \quad (1)$$

The original formation pressure is set as 30MPa, the mudstone core sample pressure seam porosity values were substituted into the formula, obtained the stress sensitivity equation under production pressure differential; and calculating separately the theoretical pressure values of the sample permeability decreases to permeability before 50% and 90% (Table1).

Table1 Sensitive equation of internal stress

sample number	k_0	b	ϕ	k_i	Sensitive equation
3	0.24	0.0095	0.0388	0.18	$k=0.18e^{-0.0095\Delta p}$
7	0.28	0.004	0.1658	0.25	$k=0.25e^{-0.004\Delta p}$

According to the production pressure difference sensitivity equation, the production pressure difference sensitivity curve was drawn, and contrast with external pressure sensitive curve (fig.3), which means the increase of external pressure and decrease of internal pressure will cause stress sensitive, but those two have difference in the degree, the variation range is relatively small in the latter .

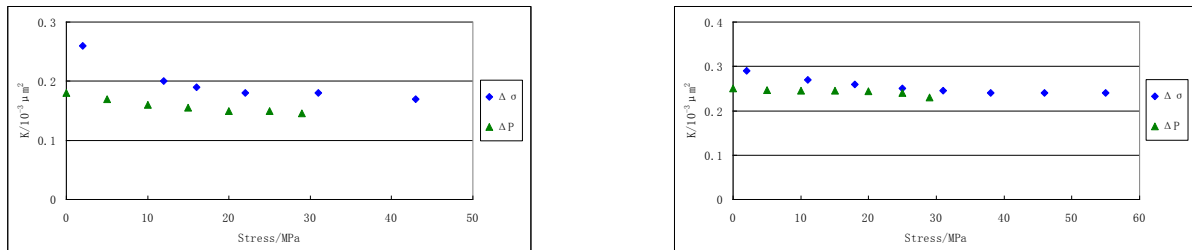


Fig.3 Sensitivity curves of external pressure and production pressure difference of mudstone sample

Table2 Critical closing pressure of mudstone samples under production pressure difference

sample number	k_i	Critical closing pressure under production pressure difference		
		Δp	50%	90%
3	0.18	35.42	15.74	30.28
7	0.25	33.16	15.47	28.57

Compared with the increase of external pressure and reduce the internal pressure (production pressure difference) obtained the closed pressure (Table2), we see the fact of when reducing the pressure, the closed pressure is smaller.

V. CONCLUSIONS

In this study, we have made a theoretical and experimental study on the closure pressure of mudstone fractures in the core samples obtained from Gu Ping No.1 well:

- (1) Applying uniaxial stress to test the stress-strain behavior of the core sample, according to its stress-strain curve, mudstone belongs to the kind of plastic-elastomer, it is prone to have the plastic deformation, by showing the fact of the difficulty to recover after the deformation of the loading stress.
- (2) Using the critical closing pressure method to have a quantitative laboratory study of mudstone fracture closure pressure, taking permeability as a parameter to characterize the degree of closure, determining the critical pressure point from the confining pressure-permeability curve which is obtained in the laboratory.
- (3) This research deduced the yield sensitive equation which is applicable to some mudstone sensitive storage layer, and is of significance in field practice, mudstone fracture closure underground, under the comprehensive influence of various factors such as the stress change and water sensitivity, force change could be only one of the main factors, if we want to obtain the complete solution, we still need a comprehensive study and analysis of each factor.
- (4) This study is established on the analysis basis of theory and experimental data, while due to the limitation of objective conditions, we can not have a comprehensive simulation of the real underground environment. The conclusion has a guiding significance, but cannot fully meet with actual situation of underground.

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