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Experiments of water's effect on mechanical properties of shale rocks

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The multiple hydraulic fracturing is an indispensable means to improve the production mass of natural gas in development of shale gas. The fracturing water consumption of a horizontal well reaches 10x10^3 m3. However, the water been injected into shale layer is not reverse discharged completely. How does this part of water stays in shale layer? What's the role it plays? And how does it have any effects on the development? We studied effects of water on shale rock mechanical properties experimentally to answer these questions.

1 Water Imbibition Experiments of Shale Rock

1.1 Water stress analysis in shale

The presence of water status in shale may have water vapor, solid water (ice, crystal water, etc.), molecular binding water, adsorbed water (water films), capillary water and gravity water. Because there are a lot of micro-nano pores in shale, as well as a large number of rich mineral soils, water will be influenced by capillary and chemical bonding force in shale, the water willbe exist in the state by adsorbed water and capillary water in the shale. Through the analysis of this force, it can provide a theoretical basis for fracturing fluid flow back's difficulties.

1.2 Macro- tests of water imbibition in shale

Shale sheets were hanged in the bottom of the balance in experiments, and partially submerged in the water.

The ability of water imbibition from the shale sheet was observed. And to analysis experimental data, and summary general rules of the water imbibition in shale combined with water micro flowing at the surface of the shale sheet.

1.2.1 Experimental prepares

(1) The shale cores were sanded into slices of diameter 25mm and height 1.5mm;
(2) The core sheets were dried at 105 ℃, to measure the quality every day until the quality no longer change;
(3) Ultra-pure water of 500ml was prepared for experiments.

1.2.2 Experimental procedures

(1) Three strings were tied to the hook on the scale in the bottom of balance, and the other ends were tied to the wire rings, and wire rings were kept balanced.
(2) Four shale clips were hung on the wire loops and keep sheets in the same horizontal level;
(3) Four shale clips were caught by racks, and keep the lower end of the core sheets at the same level until sheets stop shaking, then the balance were cleared;
(4) Core sheets were suspended in a beaker (sheets immerse into water of 3mm height), to record the mass *m* of water absorption of shale sheets, show in Fig. 1;
(5) The test recording period is about several

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minutes, to record the mass *m* of water absorption over time.

Figure1 Experimental apparatus

1.2.3 Analysis of experiments

Shale sheets in the water are forced by balance including water buoyancy and its own gravity. Before the shale sheet into the water, the balance is cleared, and then its gravity does not affect the quality of the balance after putting shale sheet into the water. After putting the sheet into the water, there arrives a new balance, including gravity and buoyancy force. The force changes of the quality of the balance:

$$\Delta F = \Delta G - F_f \qquad (1)$$

where, ΔF —quality shale sheet change of gravity and buoyancy forces，N；ΔG—quality shale sheet change gravity, N；F_f —buoyancy, N.

1.2.4 Experimental analysis

Experiments are divided into two groups with four core sheets. The first set of experiments is about 14 days, the total mass change is 1.2781g; a second set of 15-day experiment, the total mass change is about 1.4889g.

Water imbibition mass curves were plotted (shown in Figure 2), according to the experimental data. The imbibition can be divided into three stages: Firstly quality changes increase rapidly after the shale sheet was put into the water, the three-phase contact surface forms into a water ring due to interfacial tension; Secondly, rate of mass change slowly after about 1 min, the total mass change is still increasing, which means that water flow in big cracks. Finally, the final rate of mass change is very small after about five days, and finally approaches a constant value, which means that water flows through small cracks and small pores.

Experiments show that: the imbibition in surface of shale slice is very big. The mass imbibition rate is about 17%, and volume imbibition rate is about 43% which far more than porosity of shale rock of 3%. The reason is that the three-phase contact surface forms into a water ring due to interfacial tension. The moving imbibition of water can be observed by super-field depth optical microscope.

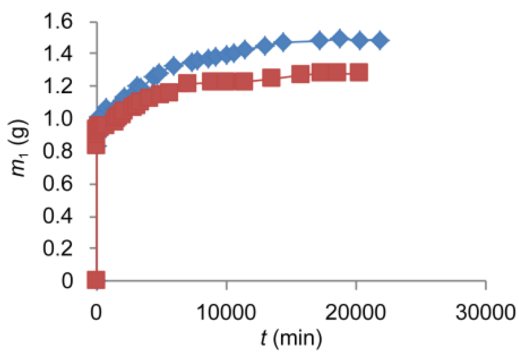

Figure 2 water imbibition on surface of shale rocks

2 Change of Shale Rock's Fracture Strength after Water Saturation

2.1 Microcosmic changes on surface of shale cores after water saturated

Core fractures were observed and contrasted by the VHX-5000 Super Depth of Field Microscope before and after saturated water. As shown in figure 3, some shale cores were qualitative judged whether water affects obviously fractures of shale. Water can dissolves the cement which is the part of shale, to form larger pores, and to promote the formation of fractures after water Saturated into shale rocks.

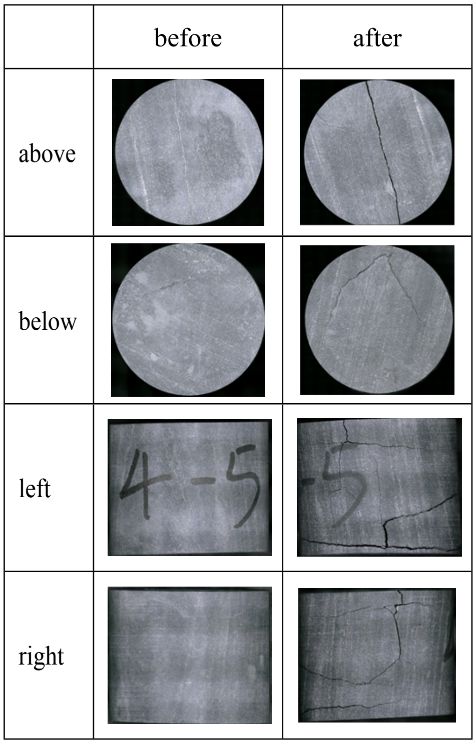

Figure 3 Shale surface fractures before and after water saturated

2.2 Porosity measurement by saturated water

According to quality changes before and after the water saturated into shale, the average absorption and the porosity[8] were calculated by formulae (2) and (3),

$$f = \frac{M_2 - M_1}{M_1} \times 100\% \qquad (2)$$

$$\phi = \frac{4 \times (M_2 - M_1)}{\rho_w \pi h_0 D_0^2} \times 100\% \qquad (3)$$

Shale's water absorption can be concluded between 2% and 3.1%, the average water absorption rate is 2.72%. The porosity is about between 5.50% and 8.02%, the average porosity is 7.02%. After saturated water in to shale rocks, water can promotes to generate the pores and cracks.

2.3 The influence of water on shale fracturing forces

By used the YES -2000j uniaxial pressure tester and DH3818 static strain testing system, the fracturing forces of water saturated shale cores and the unsaturated shale core were measured and compared.

2.3.1 forms of shale damage

There are almost damage forms of brittle splitting failures along the bedding plane of the saturated or unsaturated water shale core by uniaxial compressed. The stratification plane and micro cracks inside of shale have a large influence on the way of the fracturing, lead to the anisotropic changes of strength and deformation. As shown in figure 4, it is easier to generate fractures and lead to higher fracture degree compared with the saturated shale core.

Figure 4 the splitting failure of the shale core saturated water and unsaturated shale core

2.3.2 Maximum damage pressure

Shale rock is a kind of brittle material, in the fracturing process of the brittle material, when the stress increased, the fracture pressure of shale core will reach to the extreme points, more than the yield limit value, shale core will be damaged, it's surface will generate lots of cracks.

Experiments show that: after water saturation, the damage pressure is greatly reduced from about 30.9MPa to 10.4MPa (shown in fig.5 and Fig.6), and it is conducive to produce fractures system, so the production rate of shale gas can be improved. The imbibition water rate is about 7% of volume bigger than porosity of shale rocks because of the hydrophilic surface.

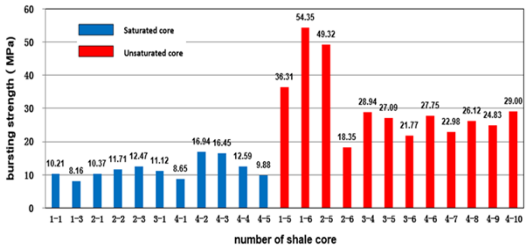

Figure 5 The damage value of shale cores with saturated water and unsaturated water

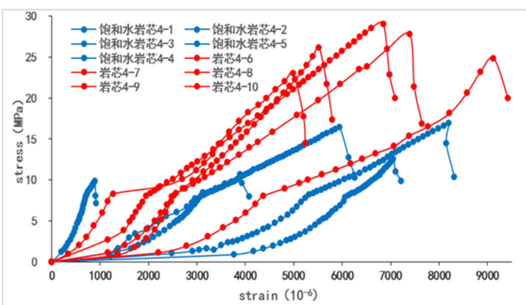

Figure 6 pressure tests curves with different stress (red curves are dry shale cores, blue curves are water saturated shale cores)

3 Conclusions

Through experiments of water imbibition in shale and experiments of the saturated shale to observe the process of crack generation, and compared failure forms and damage strength of the saturated shale cores and unsaturated shale cores, several conclusions are following:

(1) The water imbibition in shale can be divided into three stages: the first stage is that the three-phase contact surface rapidly forms into a water ring due to interfacial tension; the second stage is that water flows in big cracks; the third stage is that water flows in the small cracks and small pores.

(2) The average porosity is about 7% of the Long Maxi shale rocks used in the experiment.

(3) Water can dissolve cement which is the part of shale, and promote to develop of shale fractures after water saturated into shale rocks.

(4) The average damage value of shale cores saturated water is about 11.69MPa, while the value of unsaturated cores is about 30.57MPa, water can decrease the damage strength of the shale, and easier to generate the cracks.

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