Experimental study on inducing re-fracturing of temporary plugging agent in glutenite reservoir

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Abstract

The glutenite reservoir is a typical low porosity and low permeability reservoir with poor physical property and serious heterogeneity. During the fracturing process, temporary plugging agent is often used to open the natural micro-fractures in glutenite reservoir and increase the lateral residual oil utilization. In order to evaluate the performance of temporary plugging agent, we selected water-soluble temporary plugging agent B and oil-soluble temporary plugging agent Y to test and evaluate the softening point, melting point, solubility, salt resistance, acid resistance, plugging and reflow capability. The true triaxial hydraulic fracturing test was used to test the plugging ability of the two temporary plugging agents for the glutenite cement test block. The results show that during the fracturing process of the glutenite reservoir, the water-soluble temporary plugging agent B should be selected for the reservoir with a depth greater than 2500m or an abnormal high temperature in the shallow stratum. For strata with depth less than 2500m, oil-soluble temporary plugging agent Y should be selected to reduce the damage to formation pores. After comparison of true triaxial hydraulic fracturing tests, it is found that the diverting angle of water-soluble diverting agent is greater than that of oil-soluble diverting agent. Therefore, water-soluble diverting agents perform better in glutenite. To a certain extent, gravel hinders the long-distance concentrated migration of temporary plugging agent, leading to the poor diverting effect. It is recommended to use a low-density, small-particle size diverting agent.

Keywords

Re-fracturing, glutenite reservoir, temporary plugging agent

1. Introduction

The geology of glutenite reservoir is complex, with large vertical sedimentary thickness, rapid lithological changes, and maturity of structures and components, which is more difficult to develop than conventional reservoir. With the development entering the middle and later stages, the exploration of oil fields has entered the subtle reservoir exploration stage and the fine exploration stage of the old oil and gas areas. Any reservoir that can be explored has potential for development. Therefore, the exploration and development of glutenite reservoirs have been gradually recognized[1].

Temporary plugging agent can improve the drainage area, and communicate the reservoir with different permeability even some unused reservoirs at utmost. So it is gradually popularized and applied[2] in major oilfields, however, the application of temporary plugging agents in glutenite reservoir is still rare. Therefore, it is necessary to choose suitable temporary plugging agent in glutenite reservoir. At present, the evaluation methods of temporary plugging agent are mostly by testing the melting point, the softening point, the rheological characteristic, the temperature resistance, the solubility, the acid resistance, the salt resistance and so on[3], or use the core experiment to evaluate the influence of the diverting agent concentration and injection volume on the effect of temporary plugging agent[4]. The effect of temporary plugging agent in glutenite is lack of experiment, and the effect of temporary plugging agent in the core in three-phase stress state is not tested.

This paper evaluated the properties of two kinds of diverting agents such as melting point[5], the softening point[6], the rheological characteristic[7], the temperature resistance, the solubility, the acid resistance[8], the salt resistance[9] and so on through laboratory experiments, and evaluated the influence of the diverting agent concentration[10] and injection volume[11] on the effect of temporary plugging agent through core experiment, and selected diverting agent suitable for different conditions according to the laboratory test and core experiment results[12]. According to the effect of the diverting agent in the glutenite samples by true triaxial hydraulic fracturing test[13], the extension of the re-fracture in the glutenite and conventional fine sandstone samples was summarized[14]. It was evaluated whether different kinds of diverting agents with various concentration can produce fractures that meet the requirements of field under different horizontal stress difference conditions, so that the type and concentration of diverting agents were optimized.

2. Experimental content

2.1 Experimental materials and instruments

Experimental materials and instruments include: oil-soluble temporary plugging agent Y, water-soluble temporary plugging agent B, glutenite core, sodium chloride, sodium hydroxide, concentrated hydrochloric acid, polyacrylamide, flasks, beakers, SHZ-D (III) cycle Water type multi-purpose vacuum pump, DHG-9070A type electric thermostatic blast drying box, DZF-6020 type vacuum drying box, six-speed rotational viscometer, 85-2A constant temperature magnetic stirrer and core flow experimental device.

2.2 Basic performance requirements of temporary plugging agent

(1) It Can effectively plug the existing fractures but not penetrate into the pores of the formation and thus avoid plugging the rock pores.

(2) High strength. It has a high pressure bearing capacity, and its strength is higher than the fracture pressure of the formation; At the normal temperature, the diverting agent in the fracture is solid particle with certain hardness and strength, appearing brittle failure under stress and not sticking the pump. When the temperature reaches a certain value, the diverter particles soften and appears plastic deformation under stress[15].

(3) It has liquid solubility, and its density is greater than that of fracturing fluid, preventing the temporary plugging agent from floating on the surface of the fracturing fluid during construction[16].

(4) During hydraulic fracturing drainage and swabbing, the diverting agent in the fracture can be dissolved and discharged. Therefore, the temporary plugging agent should contain surfactant, which is beneficial to the drainage.

(5) Form a filtrate cake. The filtrate cake can be formed in the formation, with a high plugging rate and a good blocking effect.

(6) A good temperature resistance. It will not dissolve very quickly in the high temperature environment, otherwise it can not reach the purpose of plugging[17].

(7) Time is controllable. The required pressure and plugging time can be controlled by the application amount, composition, and particle size [18].

2.3 Comparison of performance evaluation of two temporary plugging agents

Measurement of melting point and softening point of temporary plugging agent

① Poured the particles of water-soluble temporary plug B and oil-soluble temporary plug Y into two 250ml beakers。

② Put beaker into DHG-9070A electric thermostatic blast drying oven for heating. During the process of increasing temperature, we constantly used glass rods to touch particles of temporary plugging agents to determine when they softened. At the same time, we recorded the temperature of two temporary plugging agents beginning to appear the phenomenon of dilution and discoloration, that is, the softening point of two temporary plugging agents.

③ After confirming the softening point, continued to increase the temperature. When the diverting agent is in a molten state and can flow rapidly, record the temperature at that time as the melting point. The test results are shown in Table 1.

Table.1 Temporary plugging agent general performance table

Name	Particle Density /(g/cm3)	Softening Point /℃	melting point /℃	Solubility (Kerosene or water)	color
Y	2.05	37.4	70	oil	Yellow particles
B	0.63	>110	>110	water	Black powder

Rheological characteristic determination of temporary Plugging Agents

If temporary plugging agent shows obvious shear thinning when it flows in the stratum, it shows that it has good injectivity[19]. Once the flow stops, the structure will recover. In order to test the rheological characteristic of the temporary plugging agent, temporary plugging agents with different concentration were heated in water bath to 50℃ until they were completely dissolved. Determine the rheological properties at different concentrations using rheometer and observed whether the shear rate was decreased with increasing viscosity.

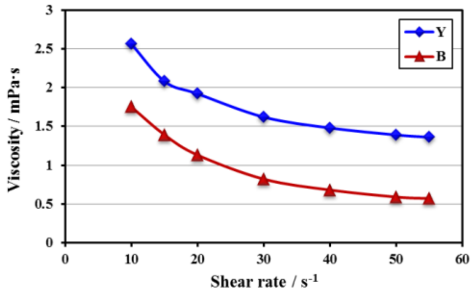

Fig.1 Shear dilution of temporary plugging agent with a concentration of 300mg/L

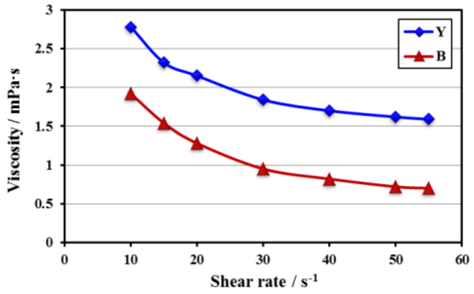

Fig.2 Shear dilution of temporary plugging agent with a concentration of 500mg/L

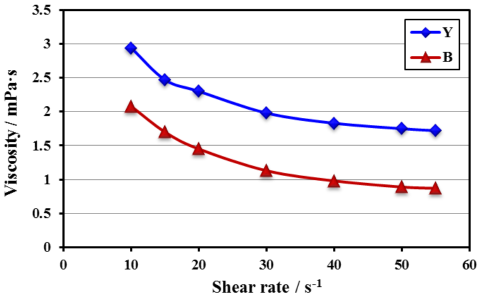

Fig.3 Shear dilution of temporary plugging agent with a concentration of 800mg/L

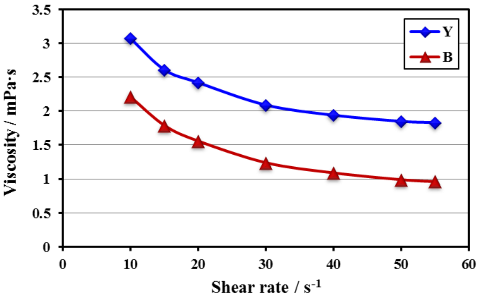

Fig.4 Shear dilution of temporary plugging agent with a concentration of 1000mg/L

From Fig. 1 to Fig. 4, the viscosity of temporary plugging agent decreases with the increase of shear rate, showing a strong shear thinning property. Moreover, at low shear rate, the viscosity decreases fast with the increase of shear rate. For example, at a temporary plugging agent concentration of 1000 mg/L, when the shear rate rises from 10 (l/s) to 20 (l/s), the viscosity of Y decreases from 3.07 mPa·s to 2.42 mPa·s, and the viscosity of B decreases from 2.22 mPa·s to 1.56 mPa·s. At high shear rate, the viscosity of temporary plugging agent decreases slowly with the increase of shear rate. At a temporary plugging agent concentration of 1000 mg/L, when the shear rate rises from 40 (l/s) to 50 (l/s), the viscosity of Y decreases from 1.94 mPa·s to 1.85 mPa·s, and the viscosity of B decreases from 1.09 mPa·s to 0.99 mPa·s. It can be clearly seen from the chart that the oil-soluble temporary plugging agent Y and water-soluble temporary plugging agent B have good shear diluent.

Solubility of temporary plugging agent

(1)Experimental procedure

①Measured the quality of temporary plugging agent particles。

②The dissolution time of two different types of temporary plugging agents was measured in a constant temperature water bath at 20℃, 50℃, 70℃, and 90℃, respectively. Took five pieces of temporary plugging agent of the same specifications and put them in five containers with 100 mL of different solutions (clean water, alkaline water with a concentration of 5%, acidic water with a concentration of 5%, saline water, guanidine gum fracturing fluid). Within 0~5 hours, measured the quality of the temporary plugging agent every 25 minutes until all the materials were dissolved.

③Put the same liquid into each beaker and measure it. Vacuum filtration was carried out at different time intervals to measure dissolution rate. Then the average measured dissolution time was drawn into curves.

（2）Analysis of experimental results

The results of oil-soluble temporary plugging agent Y indicate that the higher the temperature is, the higher the solubility of oil soluble temporary plugging agent is in the same time period. But overall, the solubility is not large, when the temperature is at 20 °C, the maximum solubility is less than 16%; At 70 °C, the maximum solubility is less than 27% (Figure 5), and when the temperature is maintained at 90°C, the maximum solubility does not exceed 30%. At the same temperature, the fracturing fluid has a high solubility, and the solubility in 5% acid solution is high under all temperature conditions. On the contrary, the solubility of oil-soluble temporary plugging agent is the lowest in the 5% aqueous alkali. Within 0~1 hours, the dissolution rate of oil-soluble temporary plugging agent is the largest under different temperature conditions, and the dissolution rate varies little between 2~5h, basically remaining at a fixed value. At the same time, the dissolution rate of the temporary plugging agent in the same temperature condition and in different solution types is basically the same at the same time period. And the dissolution rate of temporary plugging agent is almost unchanged with time after 1 hour in the same temperature condition and the same solution types.

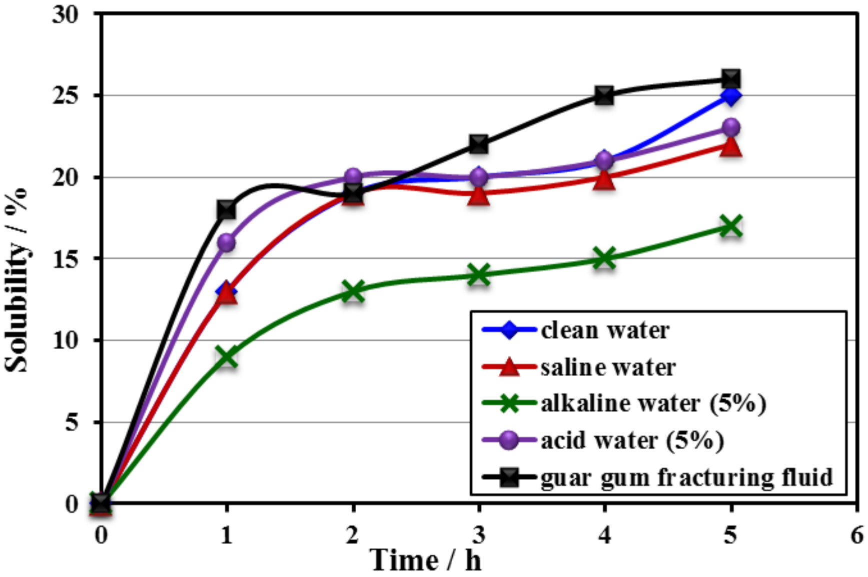

Fig.5 Dissolution curve of oil soluble temporary plugging agent at 70 ℃

The solubility of the water-soluble temporary plugging agent B increases with increasing temperature. Under the condition of 20℃, the solubility of the water-soluble temporary plugging agent is less than 20% at 0.5 hour. Under the condition of 70℃, the solubility in fracturing fluid is about 25% at 0.5 hour, and the others are more than 40%. At 90℃, the lowest solubility in the fracturing fluid has also exceeded 60% at 0.5 hour. At the same temperature, the temporary plugging agent has the lowest solubility in fracturing fluid and the highest solubility in clear water. In general, the solubility of the water-soluble temporary plugging agent in the above solution is as follows: clear water> saline water > 5% alkali> fracturing fluid. The dissolution rate of water-soluble temporary plugging agent B in water is the largest and basically does not change with time. The dissolution rate of water-soluble temporary plugging agent in saline water is similar to that in water, only a little slower.

The dissolution rate of temporary plugging agent in 5% alkali, 5% acid and fracturing fluid is that the dissolution rate of temporary plugging agent is larger during the initial period of time, and the dissolution rate of temporary plugging agent begins to slow down after the later period.

Determination of acid resistance of temporary plugging agents

(1)Experimental process

At 20℃, 1 gram of oil-soluble temporary plugging agent Y and 1 gram of water-soluble temporary plugging agent B particles were immersed in dilute hydrochloric acid with concentration of 10% respectively, then acid solution was filtered out and two kinds of temporary plugging agent granules were dried by filter paper, also being washed and dried. The dissolution rate of plugging agent granules in kerosene and water was measured respectively [20].

(2)Acid solubility analysis of temporary plugging agent

The experimental data of remaining oil-soluble temporary plugging agents after immersion are shown in Table 2.

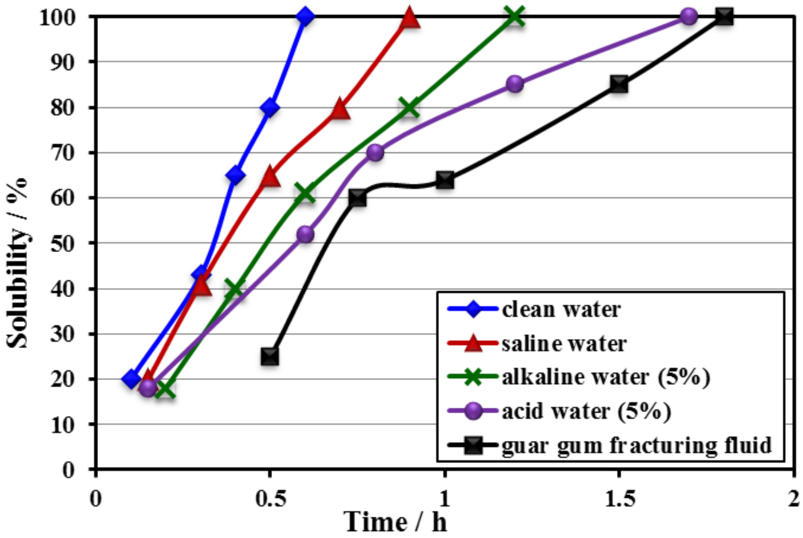

Fig.6 Dissolution curve of water soluble temporary plugging agent at 70℃

Table 2.Experimental data of Acid solubility

soaking time/h	oil solubility of oil-soluble temporary plugging agent /%	water solubility of water-soluble temporary plugging agent /%
1	99.93	98.83
2	99.92	99.90
3	99.93	99.92
4	99.91	99.89
5	99.87	99.85

From Table 2, it can be seen that as the soaking time increases, the solubility of the temporary plugging agent after immersing in 10% hydrochloric acid in kerosene or water does not change much with that before soaking, and remains basically stable. It shows that the temporary plugging agent after pickling can still be dissolved in kerosene or water.

2.3.5 Determination of saltresistance of temporary plugging agent

(1)Experimental process

①Configure formation water with different mineralization with NaCl

②At 90℃, 1 gram of oil-soluble temporary plugging agent Y and 1 gram of water-soluble temporary plugging agent B were added to the NaCl solution for 15 minutes.。

③After 15 minutes, brine was filtered off, and the surface of the particles of the two temporary plugging agents was dried with filter paper, then washed with fresh water and dried. At last, we measured the dissolution rate of remaining two kinds of temporary plugging agent particles in kerosene and water.

(2)Analysis of experimental results

From table 3, we can see that with the increase of mineralization, the solubility of water-soluble temporary plugging agent is higher than that of oil-soluble temporary plugging agent. The oil solubility and water solubility of temporary plugging agent particles after soaking in saline water are not much different from those before soaking. It shows that the oil-soluble temporary plugging agent Y and water-soluble temporary plugging agent B in the stratum with high salinity or in the high salinity formation water, the properties will not change because of the mineralization and thus affect its blocking effect.

Table 3. Saltresistance of temporary plugging agent at 90℃

mineralization	Solubility of oil-soluble temporary plugging agent /%	oil solubility of oil-soluble temporary plugging agent /%	Solubility of water-soluble temporary plugging agent /%	water solubility of water-soluble temporary plugging agent /%
500	12	98.88	50	96.98
1000	12	98.91	55	99.71
5000	13	99.94	62	98.92

Analysis of core experimental results of temporary plugging agent

(1)Effect of temporary plugging agent injection concentration on temporary plugging and unplugging effects

Tested the influence of temporary plugging agent particle concentration on the temporary plugging and unplugging effect, with core permeability of 0.982×10-3μm2, the experimental temperature of 70℃, the injected volume of 3PV, and the output volume of 50PV. The results are shown in Table 4.

Table 4 Temporary plugging and unplugging data with different concentrations

injection concentration /%	temporary plugging rate of oil-soluble temporary plugging agent /%	unplugging rate of oil-soluble temporary plugging agent /%	temporary plugging rate of water-soluble temporary plugging agent /%	unplugging rate of water-soluble temporary plugging agent /%
1	89.58	94.63	73.05	95.37
3	93.38	92.09	93.35	89.29
5	94.70	90.00	94.89	86.86

Table 4 shows that the plugging rate of the oil-soluble temporary plugging agent Y is better than that of the water-soluble temporary plugging agent B at different concentrations, while the unplugging rate of the water-soluble temporary plugging agent B is slightly higher than that of the oil-soluble plugging agent Y. The temporary plugging agent with a concentration of 3% to 5% has good temporary plugging effect in the glutenite reservoir.

(2)Influence volume of temporary plugging agent on temporary plugging and unplugging effect

The injection volume of different temporary plugging agents will have an effect on the plugging and unplugging of the core [21]. Tested the influence of temporary plugging agent injection volume on the plugging and unplugging effect, with experimental temperature of 70℃, the injection concentration of 3% and the output volume of 50PV. The results are shown in Table 5.

Table 5 Temporary plugging and unplugging data with different injection volume

injection volume /PV	temporary plugging rate of oil-soluble temporary plugging agent /%	unplugging rate of oil-soluble temporary plugging agent /%	temporary plugging rate of water-soluble temporary plugging agent /%	unplugging rate of water-soluble temporary plugging agent /%
1	90.99	94.85	86.43	92.48
3	92.80	92.76	93.05	89.25
5	94.44	91.71	94.11	86.54

As can be seen from Table 5, as the temporary plugging agent injection volume increases, the temporary plugging rate gradually increases. However, the unplugging rate decreased with the increase of injection volume. The plugging rate of oil-soluble temporary plugging agent Y is generally better than that of water-soluble plugging agent B.

2.4 Physical model experimental study of diverting repeated fracturing in the old glutenite fracture

Experimental program

The raw materials of the specimens contains cement, water, sand and gravel (various shapes and sizes, match according to the obtained core data), admixtures, steel pipes and so on. Equipments include mixer, insulated box, balance and square grinding tools.

The mortar was prepared in the laboratory after its materials proportions were determined. The mixture of cement, sand and gravel will be stirred for a while using a small blender, then water was added into the blender with the addition of water reducing agent. After the mortar was prepared, it needed to be injected into the mould for molding. When the mortar was injected into the specified position in the mould, put the steel pipe of the simulated wellbore into the mold before pouring.

After the cementation of cement block, servo control rock mechanics triaxial test system was used to carry out fracturing test. The experiment system is mainly composed of hydraulic pump group, the triaxial stress loading system, main control computer. Firstly, the initial fracturing process was used to create fracture, the cement block was placed into the diverting agent and let it flow into the fracture under the condition of no confining pressure, then observed the effect of the steering agent on the specimen after re-fracturing process.

Table 6 The experimental scheme of diverting within fractures

Serial number	Core number	Diverting agent	Concentration	Crustal stress	Remarks
1	1#	B	3%	20/15/13	glutenite
2	2#	Y	3%	20/15/13	glutenite
3	3#	B	3%	20/15/13	Conventional packsand
4	4#	B	3%	20/15/10	glutenite

Experimental results

After the initial fracturing of the core, it is noted that the fractures extends along the main stress direction. Subsequently, the diverting agent was injected into the No.1~5 cores, and then the cores were fractured again. The experimental results are as follows.

After adding water-soluble and oil-soluble diverting agent with the concentrating of 3%, the re-fracturing fracture formed in the No.1 core (Fig. 7) and No.2 core (Fig. 8) extended along the minimum main stress direction. The diverting fracture of No.2 core is at the position of wellhole. Compared with No.2 core, The diverting fracture of No.1 core is slightly away from the wellhole. This is related to the larger particles and higher density of oil soluble temporary plugging agents and the difficulty of loosening them to the deep position of glutenite.

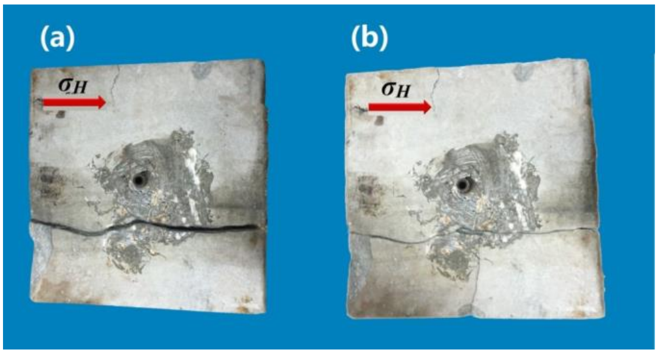

Fig.7 Re-fracturing fracture diversion of No.1 core

The fracture in No.3 core (Fig. 9) expanded along the minimum principal stress direction after being blocked by the water-soluble diverting agent. Contrasting No.1 core and No.3 core, it is found that the re-fracturing fracture of No.1 core is near the wellbore, and that of No.3 core is further away from the wellbore. Perhaps the reason is that the gravel has prevented the fractures from diverting to some extent, or the gravel prevents the water-soluble diverting agent from filling the fracture tip through the fracture and causing a large number of reagents to gather around the wellbore, resulting that the re-fracturing fractures closer to the wellbore.

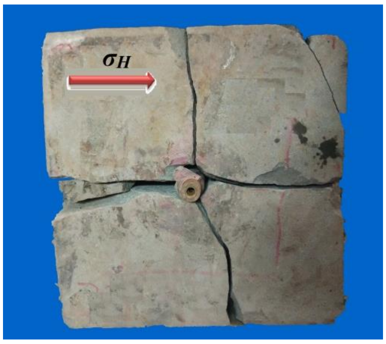

Fig.8 Re-fracturing fracture diversion of No.2 core

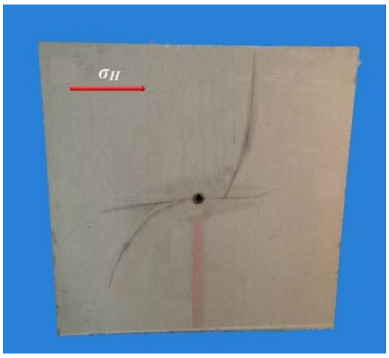

Fig.9 Re-fracturing fracture diversion of No.3 core

Fig.10 Re-fracturing fracture diversion of No.4 core

Although the re-fracturing fractures of No.4 core (Fig. 10) extends along the minimum principal stress direction, the diverting fracture is much closer to wellbore and the diverting angle is much smaller than No.1 core, showing that it is more difficult to cause diversion and the diversion angle is bigger after stress difference increasing.

3. Conclusion

The solubility of water-soluble temporary plugging agent B in 10% acid is large, which does not meet the requirement of temporary plugging agent as acidizing temporary plugging. Meanwhile, the water-soluble temporary plugging agent B has strong resistance to high temperature, indicating that it is suitable for high temperature formation and deep strata.

Core experiment shows that for gravel core, the oil-soluble temporary plugging agent Y and water-soluble temporary plugging agent B meet requirement of the minimum temporary plugging rate, and the plugging rate is high. Therefore, during the process of fracturing operation in sand and gravel reservoir, the water-soluble temporary plugging agent B should be selected for the abnormal high temperature oil and gas reservoirs with depth greater than 2500m or shallow stratum. For the depth less than 2500m, the oil-soluble temporary plugging agent Y should be selected to reduce the damage to the porosity of the formation.

After true triaxial hydraulic fracturing tests, it is found that the diverting angle of water-soluble diverting agent is greater than that of oil-soluble diverting agent. Therefore, in the gravel rock, the performance of water-soluble diverting agent is better. To some extent, gravel obstructs the long-distance concentrated migration of temporary plugging agents, leading to the worse diverting effect. So it is suggested to use low density and small size turning agent. The smaller the stress difference is, the greater the angle of the diverting is.

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