EXPERIMENTAL STUDY OF SELF-SUPPORTING PROPERTIES OF SUPERCRITICAL CO_2-INDUCED FRACTURES

by

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In this paper, CO_2 fracturing experiments were carried out in a conglomerate to analyze the fracture morphology, and fracture surface characteristics, and discuss the fracture self-support mechanism. Results indicate that compared to supercritical CO_2 (SC-CO_2) fracturing, SC-CO_2 shock fracturing can break through the limitations of in situ stress to develop more complex fractures. The SC-CO_2 shock fracturing induced rougher fracture surfaces. As a direct result, rougher fractures with larger apertures have greater permeability and conductivity, approximately three times that of SC-CO_2 fracturing. This is because, under the influence of impact, shear misalignment allows rough fracture surfaces to self-support and exfoliated particles to act as proppant, allowing SC-CO_2 fracturing to form self-supported fractures with greater aperture and permeability.

Key words: *conglomerate, SC-CO_2 fracturing, surface characteristics, self-supporting*

Introduction

With the progress of exploration and development technology, conglomerate reservoirs with proven oil and gas resources of more than 100 millionns are being used as the main force of development in China [1, 2]. Mahu Oilfield, the largest conglomerate oil field in the world, is rich in oil and gas reserves [3]. Conventional hydraulic fracturing is limited due to the strong reservoir heterogeneity and water sensitivity. Therefore, CO_2 was used as a fracturing medium to explore low injury fracturing modes with no or little water [4, 5]. The SC-CO_2 fracturing is proposed as an environmentally friendly method that forms a complex fracture network without damaging the reservoir, while effectively improving fracture expansion and allowing for CO_2 burial in the formation [6-8]. A large number of indoor experiments and numerical simulations have been carried out on shale, sandstone, granite, and coal rock [9-12]. However, at present, the mechanism of self-supporting fracture caused by SCCO_2 is not clear, so SC-CO_2 fracturing experiments are carried out on conglomerates by quasi-static and energy-accumulating loading, respectively. The fracture morphology and fracture surface characteristics were analyzed. The self-supporting mechanism wasdiscussed, which provides a theoretical basis for SC-CO_2 fracturing conglomerate.

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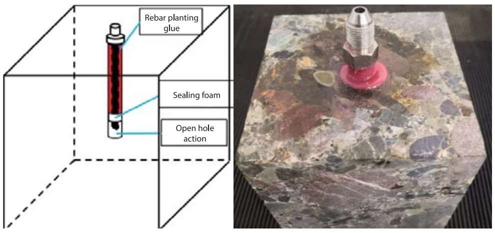

Figure 1. Schematic diagram of open hole completion and rock sample

Rock sample

The rock sample used in the experiment is the outcrop of the Baikouquan formation in Mahu Sag. The irregular outcrops were cut into cubes with a prism length of 100 mm. To avoid hydration and collapse, alcohol is used as a coolant in the cutting process. Select a surface as the stress vertical surface, drill holes to form a wellbore, insert a stainless-steel pipe to simulate the borehole and consolidate with rebar planting glue, and set aside an open hole section at the bottom to simulate the open hole completion technology of on-site construction, as shown in fig. 1.

Equipment

The SC-CO_2 supercharging device uses compressed air as the power to pressurize the CO_2 and store it in a high pressure vessel with a maximum working pressure of 100 MPa, a volume of 3000 mL, and a pressurization ratio can reach up to 1:140.

To simulate the stress state of rock in the reservoir, the true triaxial fracturing experiment device is used, as shown in fig. 2(b). The device can provide a confining pressure of up to 50 MPa, and the side length of the cubic sample can vary from 100-400 mm. At the same time, the device is equipped with electric heating rods, and the temperature control range is 20-200 °C.

Figure 2. The SC-CO_2 fracturing experiment system; (a) SC-CO_2 supercharging device and (b) true triaxial fracturing device

Experimental methods

To compare the fracture morphological characteristics of SC-CO_2 fracturing under quasi-static loading and shock loading, two experimental schemes are designed.

In the form of quasi-static loading, the fracturing pipe-line is directly connected to the wellbore. The pressure acts on the inside of the rock sample through the connected pipe-line. When the pressure increases to the initiation pressure, a fracture occurs inside the rockand propagates to the surface. The CO_2 in the pipe-line will leak along the fracture and the fracturing complete.

Based on quasi-static loading, an accumulated energy storage tank and pneumatic valve are introduced to realize shock loading. The pressurized SC-CO_2 is first stored in the tank.

When the pressure reaches the set value, the high pressure SC-CO_2 is released and acts on the rock, forming the impact effect.

Fracture morphology

The fracture morphology is shown in fig. 3. In C1, the fracture initiated near the wellbore and extended in the direction of the maximum principal stress without bifurcation or significant deflection.The fracture produced by the quasi-static fracturing is relatively simple, and the propagation direction is greatly affected by the stress.

In C2, during crack propagation, secondary fractures were created and deflected upon encountering gravel. Fractures break through the stress limitations and run through the entire rock sample. Fractures formed by shock fracturing have greater widths while branching and microfractures are formed. In addition, the particles on part of the crack surface fall off under the impact. The SC-CO_2 shock fracturing has a stronger destructive effect on rock samples, and the actual width and length of the main fracture are also longer.

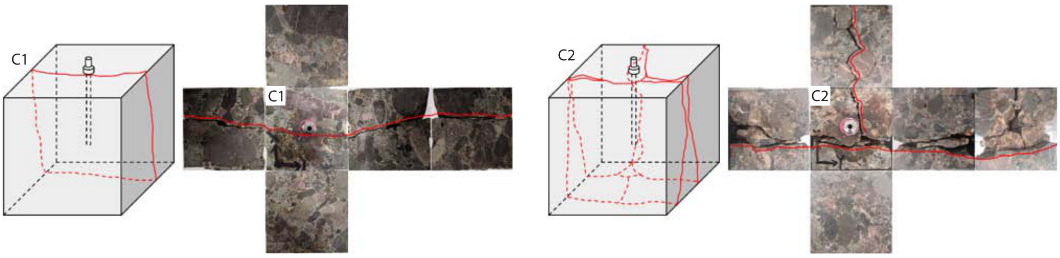

Figure 3. Fracture morphology under quasi-static loading and shock loading

In conglomerates, there are mainly three fracture patterns: penetrating gravel, winding gravel, and stopping gravel, fig. 4. The results showed that under quasi-static loading, most of the fractures propagated around the gravel. While undershock loading, the high pressure fluid provided enough energy for the fracture expansion, and produced the fracture through the gravel, as shown in fig. 5.

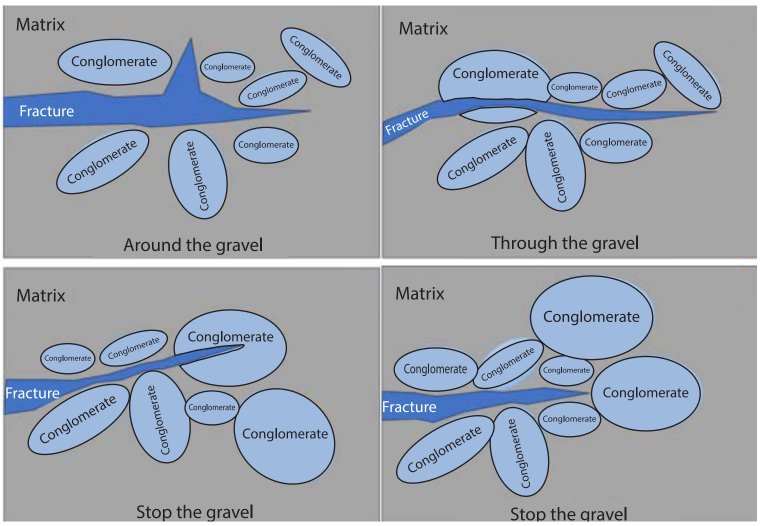

Figure 4. Schematic diagram of conglomerate crack propagation

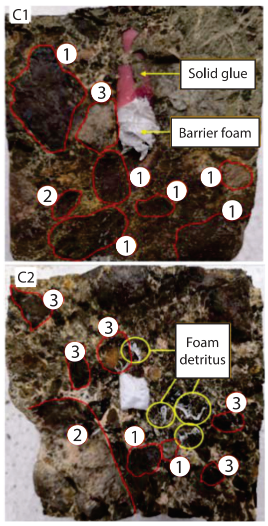

Figure 5. Fracture surface of quasi-static and shock fracturing

Fracture surface characteristics

The scanning results of the crack surface are shown in fig. 6. The average roughness of the upper and lower fracture surface of SC-CO_2 quasi-static loading fracturing is 112 μm and 129 μm, while that of SC-CO_2 shock fracturing is 239 μm and 288 μm. The fracture surface produced by shock loading is rougher than quasi-static loading.

The main reason for this result is that the fracture extensionwasregular due to the influence of stress difference and weak surface in the process of quasi-static loading. The CO_2 can easily enter microcracks owing to its special properties. When the fluid pressure continues to increase to the fracture initiation pressure, it will induce the original micro-fractures to expand, thus reducing the roughness and fracture width of the fractures. However, during the shock loading, the high pressure CO_2 is instantly released, and a larger instantaneous stress wave will be formed, which is much larger than the fracture initiation pressure. The constraint on the crack initiation will be reduced. The crack width is also increased by the impact of higher impact pressure, and the crack surface roughness is higher.

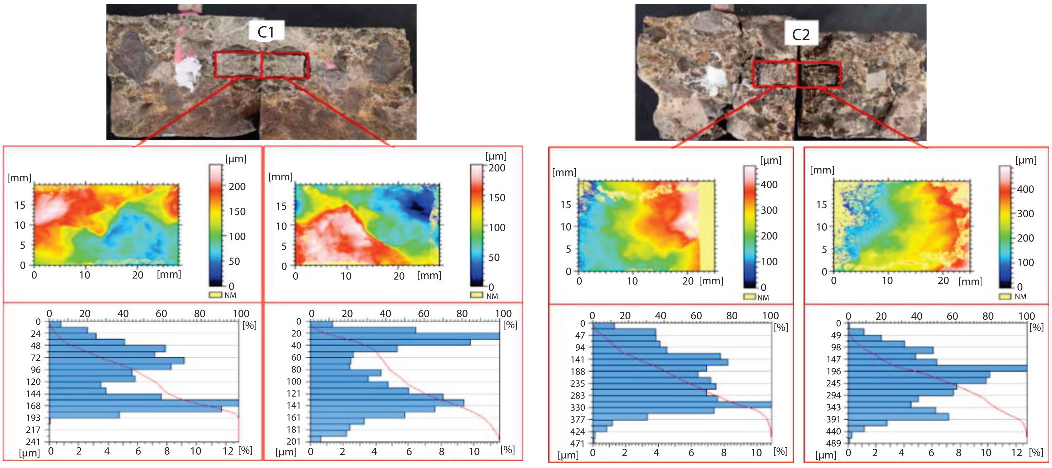

Figure 6. Scanning results and depth distribution map

Analysis of self-supporting mechanism

Previous explorations related to explosive fracturing have shown that it generates a large stress wave that induces misalignment of the formation, resulting in the formation of self-supporting fractures. The SC-CO_2 shockfracturing has similar principles, and whether it can also produce self-supporting fractures remains to be investigated.

The coincidence degrees of the crack surface are shown in fig. 7. The results showed that the cracks induced by quasi-static loading were in better match, and the degree of overlap was much higher than that of shock loading. Because the stress wave generated by the instantaneous release of high pressure fluid in shock loading will cause the fracture to stagger. At the same time, some of the weakly cemented particles are released and act as proppants within the fracture to support the fracture.

Conclusion

The SC-CO_2 shock fracturing generated more complex fracture morphology than quasi-static loading. Secondary fractures are created and fractures penetrate or go around gravels.

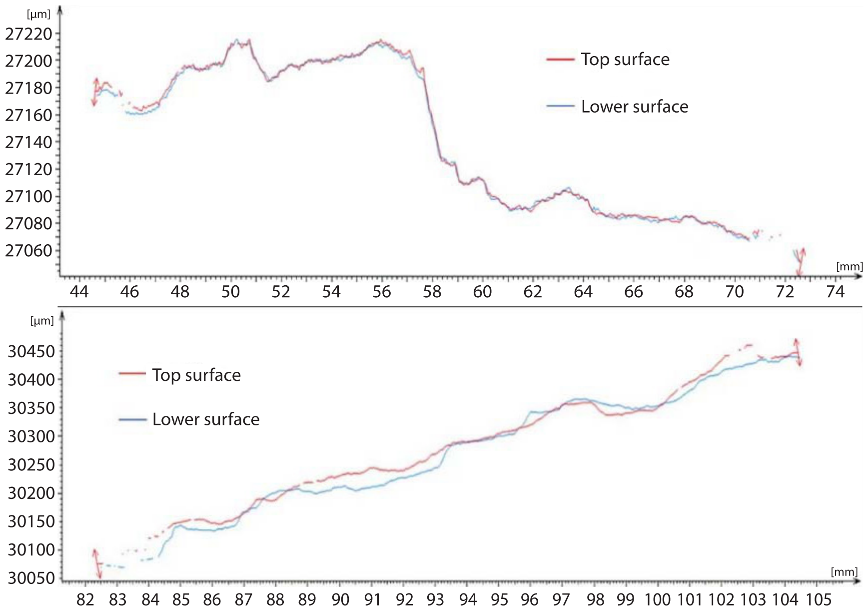

Figure 7. The height difference of the fracture surface at the same position

The SC-CO_2 shock fracturing broke through the limitations of stress and produced a rougher fracture surface, with an average height of about twice that of quasi-static loading. The high pressure impact in the shock loading mode caused relative displacement of the fracture surfaces while dislodging the weakly cemented particles, which play the role of proppant. Both of these make the cracks self-supporting.

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