Study on the law of artificial crack propagation and fracturing technology in strong heterogeneous conglomerate strata: a case study of the Mahu glutenite in Xinjiang Oilfield

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Abstract. The glutenite reservoir of the Triassic Baikouquan Formation in the Mahu sag with a large amount of resources, is the main block for Xinjiang oilfields and even domestic oil production in recent years. The reservoir is characterized by deeper burial, fewer natural cracks, low fluidity, high pressure coefficient, high horizontal stress difference and special lithology. For these geological problems, researches on fracture extension law, proppant placement law and fracturing technology have been developed to form an integrated volume fracturing technology of heterogeneous glutenite geological engineering. The contributions are as follows: (1) The lithofacies reservoir in Mahu includes matrix support, particle support and mixed support, which makes the conglomerate reservoir have large differences in many respects. The mechanical parameters of granular-supported conglomerate are higher than those of complex-base-supported conglomerate, and the brittleness index is higher. (2) Fracture regularity of glutenite varies greatly at different scales. As the ratio of fracture size to gravel size enlarges gradually, the influence of gravel on fracture extension weakens. (3) The fracture roughness of glutenite has great influence on fluid flow and proppant migration. The sand-laden fluid flows by fingering in small fracture. The crack with larger width is the dominant flow channel and will influence proppant placement.

1. Introduction
Glutenite reservoirs are widely distributed in China, with different degrees of distribution in the Mahu sag, Qaidam Basin and Erlian Basin in the Junggar Basin. In particular, the discovery of the Mahu large-scale conglomerate oil field in Xinjiang in recent years has become the most realistic storage and production area in China[1]. The glutenite reservoir generally has the characteristics of great changes in lithology and permeability, low porosity, poor connectivity, complex pore structure and serious heterogeneity. In the process of hydraulic fracturing, the fracture propagation model is complex and difficult to control. The crustal stress field, gravel content and particle size distribution have great influence on the crack propagation pattern, which seriously restricts the improvement of glutenite reservoir reconstruction. In recent years, a large number of scholars at home and abroad have carried out a lot of research on fracture propagation law and fracturing technology of glutenite. Li Lianchong [2] et al. studied it by numerical simulation method law of hydraulic fracturing crack propagation in...
glutenite and revealed four modes of ‘cracking, deflection, penetration and adsorption’ of conglomerate expansion cracks. Wang Hao[3] studied the influence of gravel content and size on fracture extension by physical model experiment and numerical simulation. Li Ning[4] et al. analyzed the influences of the horizontal stress difference, gravel size and distribution, fracturing fluid viscosity and pumping rate on the fracture propagation, using a large scale tri-axial fracturing simulation system. Based on the experience of similar reservoir reformation at home and abroad and the inspiration of reservoir remoulding, the author takes the glutenite reservoir in Mahu Sag of Xinjiang as the research object, and deeply studies the physical properties, lithofacies and particle size heterogeneity and their effects on mechanical properties, fracture extension and fracturing construction. The fracturing laws of glutenite under different conditions of core size, small-object model experiments and field applications are carried out by physical model experiment, and the controlling factors of crack propagation of glutenite are analyzed. Additionally, the influence of glutenite fractures with high roughness on fluid flow and proppant placement rules was studied, in order to guide the optimization of high-efficiency reservoir reconstruction technology for glutenite.

2. Studies on geological characteristics of heterogeneous glutenite

2.1. The heterogeneity of porosity
The physical parameters of the reservoir in the Bai 2 segment of the Marbei Slope are as follows: the average porosity is 7.76%, the average permeability is 1.11mD and the formation pressure coefficient is 1.11. Reservoir type in the Bai 1 segment of the Marxi Slope is low porosity and permeability: the average porosity is 10.69 %, the average permeability is 8.38 mD. The reservoirs in the Bai 1 segment of the Marxi Slope are tight oil reservoir with an average porosity of 9.52% and permeability of 2.11 mD. The pore-throat conditions have the characteristics of small pores and thin throats, e.g. the average pore-throat radius in the Ma 131 well area is 1.1μm; the average pore-throat radius in the Bai 1 segment of Ma 18 well area is 2.1μm. There is a high threshold pressure gradient in this area due to poor physical properties and pore-throat conditions with 0.14MPa/m in the Ma 131 well area and 0.017MPa/m in the Bai 1 segment of Ma 18 well area. There are different pressure systems in Mahu depression including normal pressure reservoir in Mabei area (pressure coefficient 1.1) and high pressure reservoir in Maxi area (pressure coefficient 1.5~1.7). Based on the above research results, it could be concluded that there are great difference in physical parameters and pressure among fault blocks and formations in Mahu depression. For horizontal well + volume fracturing technology, the heterogeneity of physical properties requires different in drilling and fracturing parameter optimization (borehole distance, fracture spacing and scale). It is essential for improving reservoir producing extent and recovery to improve the level and pertinence of the parameter optimization of drilling and fracturing.

2.2. The heterogeneity of lithofacies
The glutenite reservoir in Mahu depression includes three types: matrix support, particle support and mixed support. The types of lithofacies and fillings cause great differences in the physical and mechanical properties of glutenite[5]. Different types of fillings in different lithofacies lead to great differences in physical properties (permeability and porosity) especially permeability, for example, the permeability of rock samples with sand filling is as high as 42.3mD, while the permeability of rock samples with no filling is as low as 1.03 mD. On the contrary, the influence of filling type on porosity is not obvious. In mechanic properties, the differences of glutenite petrofacies have great influences on brittleness and plasticity evaluation. It is difficult to achieve complete coring of particle supported glutenite, which is fragile. In contrast, coring integrity of mixed supported glutenite is better. It shows the comparison results of different types in figure 2, which can be seen that there are obvious elastoplastic differences between the rock samples. The rock mechanics strength of mixed supported rock sample is low, showing plastic characteristics; however, it is higher in particle supported rock samples, showing obvious brittleness characteristics. Proppant embedment is the main controlling
factor of fracture conductivity in matrix cementation reservoirs, however, proppant broken is the main controlling factor in particle supported glutenite reservoirs which gravel content is high, gravel size and fracture roughness are large.

![Figure 1. Effect of filling type difference on reservoir physical properties](image1)

2.3. The heterogeneity of gravel size
The existence of gravel grain in glutenite reservoirs makes the fracture propagation quite different from that of conventional sandstone reservoirs. The size of gravel particles is much larger than that of cement and conventional sandstone. For conventional sandstone reservoirs, the size of fractures at different scales is much larger than the size of sandstone grain, which makes the law of hydraulic fracture propagation and extension in sandstone reservoirs at different scales basically consistent. There may be a great difference between the law of crack propagation obtained by experiments on small size rock samples and that obtained by large size rock samples when the size of sandstone grain is up to centimeter scale. Through the analysis of gravel grain size of reservoir in Mahu depression, we can know that there are mainly pea gravel and fine gravel in T1b1 of Ma18; the gravel are mainly pebble and fine gravel with a content of more than 50% in T1b2 of Ma18; the gravel is mainly pebble gravel with a content of 57% in T1b3 of Ma 131.

![Figure 2. The Stress-strain curves of compression tests of rock samples from different lithofacies of glutenite](image2)
3. Studies on Multiscale Fracture Extension Law of Heterogeneous Glutenite

The crack propagation is mainly controlled by ground stress field and reservoir heterogeneity and the influence of this factors exists differences at different scales. Therefore, it is necessary to study the law in different conditions.

3.1. Fracture Extension Law in core size

Fracture Extension Law in core size is studied by tri-axial fracturing simulation, using normal core samples which length is 5 cm and diameter is 2.5 cm. However, the failure features of glutenite samples with large gravel grain size and the gap between gravel and matrix (similar to natural fractures in a reservoir) are different from that of conventional sandstone. Analyzing microcosmic fracture extension of core samples in tri-axial fracturing experiments, it is shown that 4 typical extended modes, caused by stress, are terminations, deflections, penetrations and attractions. It demonstrates that the hydraulic fracturing is more complex due to the existing of gravels, instead of control by stress completely. The physical simulation results shows that fracture extension is closely related to gravel strength, size, volume content and cementation. Fracturing deflections and penetrations occur mainly in the near-well area because of the higher net pressure and the faster fracture propagation rate; Fracturing terminations and attractions occur mainly at the far end of the crack because of the lower net pressure and fracture propagation rate.
3.2. Fracture Extension Law in small-object model experiments
For the glutenite reservoir in Mahu depression, the size of gravel particles is mostly less than 20 cm. It can be seen that the ratio of hydraulic fracture height to gravel particle size is between 10 and 15 times when the actual size reaches tens of meters in the height direction. The ratio of fracture size to gravel particle size at core scale is only between 1 and 2. As a result of this comparison, there are significant differences between in small-object model experiments and in core size. In this way, a larger scale physical model experiment can more accurately show the fracture extension law, as shown in figure 6. In this experiment, the size of No.5 sample is between 2 mm and 15 mm, and the track of hydraulic fracture is relatively straight, without obvious bifurcation and deflection. For No.3 sample, the biggest size reaches to 112 mm, and the gravels are jumbled up which long axis has no predominant direction. By analyzing the fracture extension law and pressure variation, the results are as follow:

1. Hydraulic fractures extend along maximum horizontal principal stress controlled by the earth stress in larger scale; In small scale, the extension of hydraulic fractures around gravel grains may change the local extension path, but it has little effect on the global scale.

2. With the increase of gravel grain size, the roughness of fracture surface increases, which makes fluid flow around more obvious in the fracture.

3. When the grain size is less than 10 mm, the transient pressure response of the fracture extension is essentially the same as that in the non-glutenite reservoir, with stationary pressure and small fluctuation; however, when the grain size is more than 15 mm, the pressure fluctuation becomes more drastic with the larger size. It indicates that larger gravel grain maybe the cause of pressure fluctuation in fracture extension or flow.
3.3. Fracture Extension Law in reservoirs

The extension law of hydraulic fracture can only be qualitatively judged by the change of bottom hole pressure in reservoirs, rather than visualization method. In order to remove the disturbing factor of frictional resistance, the field fracturing operation wells of bared tubing are chose to analyze bottom hole pressure. Taking a fracturing well of bared tubing as an example, it is in the reservoir with small-medium gravel size and its fracturing fluid is gel fracturing fluid. The fracturing construction curve is shown in figure 7. The casing pressure of the pad fluid and sand-laden fluid with low proppant concentration is basically stable while it increases a bit in the High sand concentration fracturing. It shows that it didn’t form complex fractures in the glutenite reservoir. The fractures have no effect on flow of fracturing fluid with no proppant and low proppant concentration but have a little effect on the fluid with high proppant concentration.

The gravel size has little effect on the holistic fracture extension because it is much less than the size of hydraulic fractures. More consideration should be given to the flow of sand-carrying fluid in the fracture, which is about 1cm and in the same order of the size of gravel grains, especially for reservoirs with large gravel grains. The increase of fracture roughness caused by gravel particles may make the local fracture width smaller, leading to the increase of construction pressure and even sand plugging problems.
4. Effects of particle size heterogeneity on proppant placement

The hydrofracture flow conductivity is one of the main factors of fracturing. The above research results show that gravel grains, which size is much less than fractures’ width, mainly affect the fracture roughness and the difficulty of sand injection in subsequent construction. The fracture roughness in glutenite reservoirs is shown in figure 8, unlike that of shale reservoirs and conventional sandstone reservoirs. It has a great influence on the proppant concentration and the crushed extent of proppant, which are related to the diverting ability of fracture.

There is a big difference about the migration law of sand-carrier in rough and smooth cracks respectively[8]. The carrier moves in the dominant channels by fingering when the fracture width is small, and as a result, proppants distribute unevenly. Under the condition of wide crack width, the migration of carrier is the same as that in smooth cracks and proppants distribute evenly. Hence, it is helpful to improve the effect of proppant placement by improving the dynamic crack width.
5. Optimization of heterogeneous glutenite volume fracturing

Based on the understanding of the law of conglomerate crack propagation, inverse mixing fracturing technology is used to solve the problems of high construction pressure, difficult sand addition and limited reconstruction scale. This technology uses high-viscous fluid with moderate displacement to spread long principal fractures. Through many studies and field tests, construction technology of Mahu glutenite reservoirs are as follows: Combination technique of pumping bride plug, clustering perforation and multi-stake fractured completion in casing is the main technique, and the injection method is inverse mixture of crack-maked gel, slick-water prepad and sand-carried gel. Optimized parameters are as follows: a single segment includes 2-3 clusters, the average crack distance is 30-40cm, the percent of pad fluid is 60-70%, the percent of slick water is 50-60%, the average sand ratio is 20-25%, sand volume per metre is 0.85-1.0 m³/m, the displacement of slick water is 10-12 m³/min and the displacement of gum is 8-10 m³/min. Practical application is remarkable that sand volume per segment increases from 40 m³ to more than 100 m³, the success ratio of fracture operation raises from 65% to 90% and production enhances from 10 m³/d to 40 m³/d.

6. Conclusion

(1) The strong heterogeneities of many properties including porosity, lithofacies and gravel size in the Mahu glutenite reservoirs make a great difference in mechanics behavior and the fracture extending law. This puts forward higher requirements for reservoir modification technology.

(2) The porosity of particle-supported glutenite reservoir is crisper and rougher than that of mixed-supported reservoir, causing great differences in the law of sand-carrying fluid flow.

(3) The fracture propagation varies greatly among different scales in glutenite reservoirs. With the increase of the ratio between fracture width and gravel size, the influence of gravel on fracture extension will decrease.

(4) Inverse mixing injection technologies of crack-maked gel, slick-water prepad and sand-carried...
gel is suitable for glutenite reservoir reconstruction and has remarkable application effect. It provides a model for similar glutenite reservoirs.

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