Study on proppant settlement and migration in a single microfracture

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Abstract. Micro-fractures are widely developed in deep shale gas reservoirs after fracturing. Effective support of micro-fractures is of great significance to slow down the production decline rate of shale gas Wells. When the particles enter the fracture, they can be effectively supported to provide a channel with high conductivity for oil and gas transport. The level of conductivity depends on the distribution of proppant in the fracture, so it is very important to analyse and describe the settlement, migration and placement of proppant. Therefore, based on CFD-DEM method, this paper systematically studied the migration and placement of proppant in a single rough micro-fracture, and explored the influence of related factors.

1 Introduction

According to the survey data of the Ministry of Land and Resources, the shale gas resources in Sichuan and Chongqing area can reach 27.5×1012m3, and the recoverable reserves may exceed 5×1012m3, which has broad development prospects. Due to the characteristics of high shale content and low permeability, it is necessary to form a fracture network system with main fractures, branch fractures and micro-fractures interwoven by hydraulic fracturing technology to provide high seepage channels for shale gas flow and realize industrial gas flow.

However, due to the microfracture opening is generally less than 200 μ m, commonly used proppants cannot enter, according to statistics, 60-70% of microfractures are not effectively supported. Especially in deep shale gas reservoirs, the closure pressure is high, and the self-supporting fractures formed by the micro-fractures on their own surface are difficult to form effective flow conductivity, resulting in small gas well production and rapid decline. Making microfractures play a role and realizing multi-scale fracture support is very important to increase the effective reconstruction volume of deep shale gas Wells and reduce the productivity decline rate of gas Wells. Fracture conductivity is a key index to evaluate fracturing. However, it is found in field application that fracture conductivity is often less than expected after fracturing.

Therefore, in this paper, the migration and placement of proppant in a single rough micro-fracture is systematically studied by using the discrete element CFD-DEM method, and the influence of related factors is explored to provide guidance for the reasonable selection of fracturing application parameters

2 Numerical simulation scheme design

Table 1 Research scheme for influencing factors of proppant settlement and migration in a single rough micro-fracture

Research parameter	Numerical value
Wall roughness/dimensionless	2.0、2.3、2.5
Injection rate /($m\cdot s^{-1}$)	0.03、0.05、0.1
Sand ratio /%	5、10、20
Proppant particle size /mm	0.027、0.03、0.033

In Fluent, a pressure-based solver is selected and gravity is set in the fracture height direction, acceleration is 9.8m •s^{-2}, and k-ε turbulence model is selected. The crack injection port is set as the velocity inlet boundary, the crack outlet is set as the pressure outlet boundary, and the crack wall is set as the non-slip wall boundary. The DEM solver time step is set to 1.5×10^{-7}s, and the CFD solver time step is set to 1.5×10^{-5}s.

On the one hand, when the proppant particle size is too small, the number of proppant particles increases sharply under the same sand ratio, and the DEM simulation calculation characteristics will greatly increase the simulation cost. The microfracture size is small, and the proppant will spread quickly to reach its equilibrium height, typically within 7 seconds. On the other hand, proppant particle size is small, it is easy to be carried away by fracturing fluid and cannot be laid, so this paper adopts a slightly smaller fracturing speed than the fracturing site fracturing speed of $0.05m\cdot s^{-1}$.

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Table 2 Basic numerical value of influencing factors of proppant settlement and migration in a single rough micro-fracture

parameter	Numerical value
Proppant radius/mm	0.03
Proppant density/(kg·m^{-3})	2500
Fracturing fluid viscosity /(mPa·s)	1
Fracturing fluid density/(kg·m^{-3})	1000
Injection rate /(m·s^{-1})	0.05
Sand ratio /%	20

3 The influence of wall roughness

The effects of fracture wall roughness on proppant settlement and migration were investigated by using synfrac synthetic fracture.

Two types of single micro-fractures with fractal dimension and size were created to simulate proppant placement and migration, and a group of smooth fractures were added as a reference, and the simulation results were obtained as shown in Figure 1.

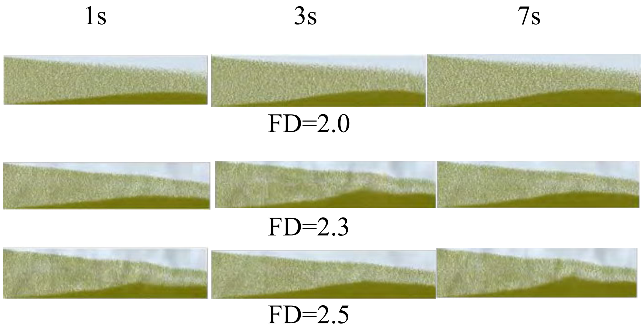


Figure 1 Distribution of proppant at different roughness at different times

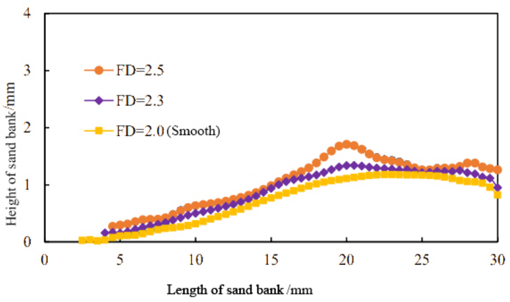


Figure 2 Comparison of sand dune morphology under different roughness

The analysis shows that in the smooth slab (FD=2.0), the proppant piles up at the fracture injection entrance under the influence of gravity, and the sand embankment in the slab gradually increases with time, and the shape of the sand embankment does not change after reaching the equilibrium height. In rough fractures, the migration path of proppant changes obviously, and the increase of roughness intensifies the particle-particle and particle-wall interactions, resulting in the orderly settlement and accumulation of proppant in rough fractures, and the shape of proppant shows multiple grooves and irregular shapes.

4 Effects of injection parameters

4.1. The effect of injection speed

The flow rate, that is, the construction displacement, will directly determine the towing capacity of the sand carrier fluid, affect the migration distance of the proppant in the fracture, and change the proppant placement form. In order to explore the influence of injection velocity on the migration and placement of proppant in a single rough fracture, the injection velocity of 0.03 m·s^{-1}, 0.05 m·s^{-1}, and 0.1 m·s^{-1} were set respectively for simulation calculation. The simulation results are shown in Figure 3. It can be seen that the sand dike in the fracture with the velocity of 0.03 m·s^{-1} is the best place, while most of the proppant particles in the fracture with the velocity of 0.1 m·s^{-1} are carried by the fluid and migrated out of the fracture.

FIG3 shows the morphological comparison curve of sand dikes in fractures at different injection rates. It can be seen that at the injection velocity of 0.03 m·s^{-1}, the proppant began to settle in the area near the well fracture, and the subsequent proppant continued to settle and deposit on the top of the sand bank or rolled over the front sand mound to the back, and most of the proppant remained in the fracture to form the sand bank. With the increase of injection speed, proppant migration energy and proppant migration distance, the initial settlement point of proppant moves back to the far end of the fracture, and the length of the sand-free zone near the fracture end increases significantly.

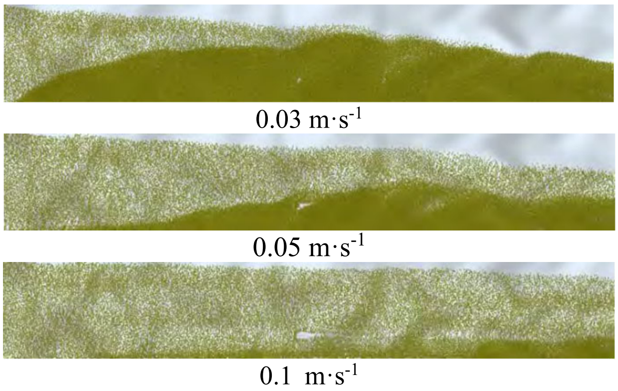


Figure 3 Proppant distribution under different injection rates

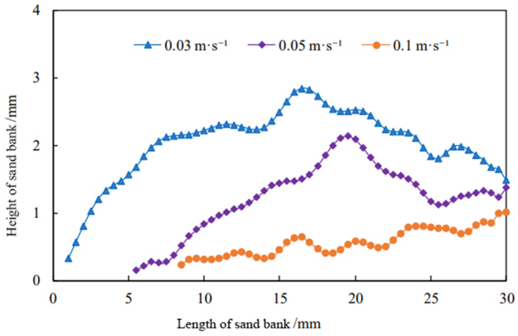
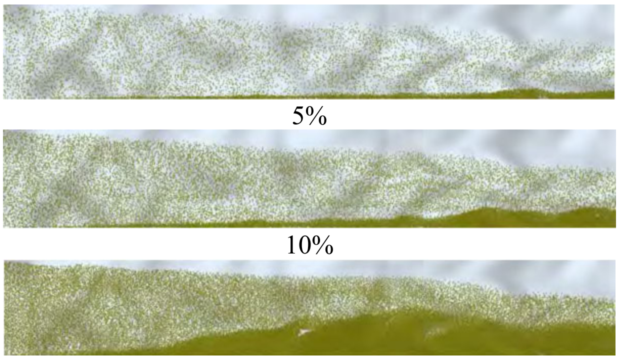


Figure 4 Comparison of sand dune morphology under Different Injection Rates

4.2 Effect of proppant sand ratio

Sand ratio is an important part of fracturing construction parameters, which can characterize the proppant concentration, the number of proppant entering the fracture per unit time, and affect the sand bank distribution. According to the conclusions obtained in Chapter 3 and the field data, this chapter sets a constant sand ratio of 5%, 10% and 20% to simulate the migration and placement of proppant in a single rough fracture under different sand ratios. Figure 5 shows the proppant distribution under different sand ratios. It can be seen that when the sand ratio is 5%, the internal placement effect of the fracture is poor. With the increase of the sand ratio, the proppant coverage rate of the sand embankment in the fracture gradually increases.


5%

10%

20%

Figure 5 Proppant distribution under different sand ratios

FIG 6 shows the morphological comparison curve of sand levees under different sand ratios. It can be seen that the placement effect of sand levees in fractures with sand ratio of 20% is significantly better than that in fractures with sand ratio of 5%. The morphological curve of sand levees in fractures with low sand ratio is more gentle.

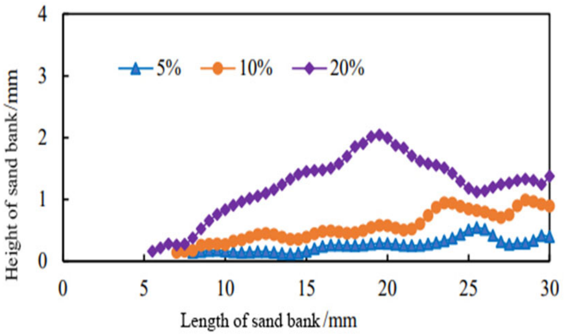


Figure 6 Comparison of sand dune morphology under Different Sand Ratios

At a high sand ratio, more particles settle to the bottom of the fracture per unit time, resulting in particle accumulation, reduced flow area, and increased horizontal velocity. As a result, the particles in the upper part of the sand dike are more likely to be carried and migrated out of the fracture, reducing the proppant coverage rate. In addition, the more particles, the higher the collision frequency between particles, which may change the vertical migration trajectory of particles and affect the settlement. Proppant migration is a multi-particle movement with interaction between particles.

With the increase of sand ratio, the amount of proppant carried into fractures in the same volume fracturing fluid increases, the particle settlement increases, and the sand bank height and length increase. However, the ability of the fracturing fluid to carry particles remains the same, that is, the increase in the number of particles at high sand ratios causes the proppant to interact more strongly and more proppant to settle from the fracture entrance.

5 Effect of proppant particle size

Particles with particle size ratios of 1/3, 0.9/3 and 0.8/3 were set for simulation. At the same time, a set of 1.2/3 cases was added to verify the reliability of the critical size of the ratio. The four sets of simulation corresponding proppant particle sizes were 0.033 mm, 0.03 mm, 0.027 mm and 0.04 mm.

Figure7 shows the distribution of proppant with different particle sizes. For 1/3, 0.9/3, and 0.8/3 proppant, no obvious bridge plugging occurred in the suture, while 1.2/3 proppant produced serious bridge plugging in the suture, and the distribution of proppant in the suture was highly heterogeneous and the coverage rate was greatly reduced.

0.027mm

0.03mm

0.033mm

0.04mm

Figure 7 Proppant distribution under different proppant particle sizes

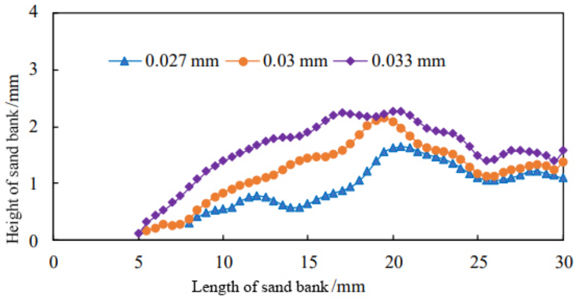


Figure 8 Comparison of sand dune morphology under different proppant particle sizes

Because the proppant with a particle size of 0.04 mm did not form an effective sand bank when the fracture was severely bridged, the sand bank curve was not compared. It can be seen that with the increase of proppant particle size, the placement of sand dike in fracture becomes better.

6 Influence of outlet opening

In fracturing operations, proppant particles are usually injected into the fracture along with the prefluid in order to get microfractures into the microfracture. In order to clarify the influence of fracture extension resistance on proppant migration and placement, three conditions were set respectively: full open outlet, blocked outlet and closed outlet to explore the influence of fracture outlet opening on the settlement and migration of proppant particles. Exit closure means that the exit surface of the crack is set as the wall surface; Outlet resistance means that a certain flow resistance is applied to the crack outlet surface, so that the fluid flowing through the outlet surface must be blocked flow; If the outlet is fully opened, the outlet is set as the pressure outlet. Figure 4-26 shows the proppant distribution patterns in the three cases. It can be seen that the proppant placement sand bank has the highest height but the shortest length in the fracture with the outlet closed.

wide-open

Resistive

Close

Figure 9 Proppant distribution under different outlet opening

Figure10 shows the comparison of sand embankment morphology at different outlet openings. From the point of view of the morphology of the sand embankment, the laid sand embankment is low and long, and the shape distribution of the sand embankment is uneven and undulating. The sand embankment in the closed outlet fracture is short and high. Considering the above two conditions, the length of the sand dike is larger than that of the closed outlet, and the surface of the sand dike is gentler than that of

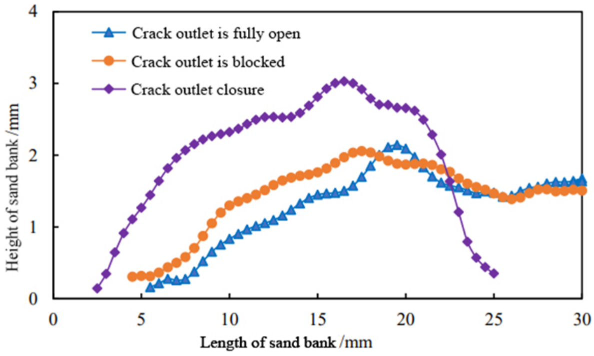


Figure 10 Comparison of sand dune morphology under different outlet opening

7 Conclusion

In this paper, the effects of fracture wall shape, injection parameters, proppant particle size, fracture outlet opening and other factors on the settlement and migration of proppant particles in a single rough micro-fracture were simulated and studied, and the following conclusions were drawn:

(1) The uneven placement of sand dikes in cracks on rough walls presents a "concave and convex" stacking, and the uneven degree of settling sand dikes increases with the increase of fractal dimension. Compared to smooth fractures, rough fractures achieve greater placement height and proppant coverage. Fracture slip can rapidly reduce placement height, length, and proppant coverage. This is because slip is easy to narrow or close the width of the fracture in the place where the fracture undulation is large, resulting in proppant bridging in this area, affecting its settlement and migration law, and enhancing the heterogeneity of the sand embankment.

(2) Compared with conventional large-diameter proppants, the suspension ability of microparticle proppants is significantly enhanced, and it is easy to be carried to the depth of fractures at low speeds. When the particles are injected, a large area without sand will appear in the fracture area near the well at a higher injection speed. The increase of sand ratio will facilitate the proppant to fill the fracture quickly and increase the proppant coverage rate of the sand bank rapidly.

(3) Increasing the particle size will enhance the proppant settlement trend and reduce the horizontal migration distance. Compared with large particle size, small particle size proppant is more likely to be carried by sand carrying fluid to remote well fractures for filling. The morphology of sand embankment formed by mixed injection is almost the same as that of paved migration formed by high proportion particles injected alone. The evaluation parameters of the sand embankment formed by mixed injection are close to those who have the highest proportion of mixed injection particles.

(4) In the process of particle proppant migration, the flow resistance at the downstream end of the fracture will affect the placement effect of the settling sand dike. The higher the exit resistance, the higher the sand bank height and proppant coverage.

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