

Effect of pulse injection on proppant distribution in fracture

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Abstract. The trend of changes in proppant concentration and fracture conductivity is essentially identical. When combined with an analysis of the average conductivity of effectively propped fractures at different locations, it becomes evident that the proppant distribution pattern becomes uneven after pulse injection. However, this pattern displays a discontinuous distribution law on the macro level. Influenced by the proppant distribution pattern, fracture conductivity exhibits significant variation at different locations. During the conventional injection process, the conductivity of fractures near the wellbore gradually decreases from proximity to distance. Conversely, the proppant phase distribution during pulse injection induces fluctuation in fracture conductivity, transitioning from proximity to distance.

Keywords: Pulse injection; Proppant distribution; Fracture propagation.

1. Introduction

The injection method has a significant impact on the effectiveness of fracturing reconstruction. To investigate its influence on fracture propagation and flow conductivity, researchers both domestic and abroad have combined theoretical and experimental studies to analyze factors such as pumping time ratios, injection volumes, and sand concentration. During on-site construction, due to the challenge of achieving a continuous change in sand ratios within the carrier fluid, the carrier fluid is segmented into pumping stages with varying sand ratios. In the conventional fracturing process, the sand-carrying fluid is continuously injected during different stages, leading to the formation of regular sand banks within the fracture. In contrast, alternate injection involves intermittently pumping the sand carrier fluid, aiming to achieve pulsed proppant injection.

Gillard^[1] found that pulse injection of sand carrier fluid during fracturing can significantly improve fracture conductivity. In order to achieve the purpose of construction, it is necessary to design the fill reasonably and analyze the proppant distribution according to the pulse injection parameters. Medvedev^[2] designed an indoor flat panel visualization experiment based on site construction parameters, and the results showed that pulse injection interfered with the proppant settlement trajectory, resulting in non-uniform distribution of the sand bank within the fracture. Malhotra^[3] alternated between two viscosity fracturing fluids during the experiment and compared the distribution patterns formed by different viscosity ratios. In order to analyze the influence of factors such as fluid viscosity, injection speed and pulse interval time on the construction effect, Gomaa^[4, 5] and Li^[6] simulated the distribution of proppant clusters in fractures of different sizes under the action of pulse sand addition by CFD model. Wen^[7] Based on the experimental results, the calculation model of the relevant parameters was established, and the change law of the conductivity of the gas-liquid two phases under different support patterns was analyzed. The study of proppant distribution patterns in fractures shows that fractures with non-uniform proppant distribution can provide higher conductivity at the same sand concentration.

The pumping time is usually calculated taking into account fracture growth and proppant distribution. Zhu^[8] studies the mechanism of conductivity under the influence of cluster spacing, and obtains the relationship between unit fracture volume and injection time

$$V = l^2 w = \frac{t_{tot} Q}{N \eta}$$
$$t_{tot} = t_p + t_f$$

Where l is the length of crack unit, mm; t_{tot} is the duration of a pulse cycle, s. t_f is the pumping time of pure fracturing fluid, s. According to the above formula, the ratio of pumping time between the sand carrier fluid and the middle top fluid can be characterized

$$\tau = \frac{t_p}{t_f} = \frac{\pi(r/l)^2}{1 - \pi(r/l)^2}$$

It can be seen from the study that r/l ranges from 0 to 0.5, which represents the stability of the support cluster. The appropriate time ratio τ can be obtained by calculation, which can not only satisfy the stability of supporting clusters, but also provide high conductivity. In summary, when calculating the pulse interval, optimizing fracture conductivity is the ultimate goal, cluster distribution is the main criterion, and the proppant transport model in the pumping stage is the main criterion, which makes the analysis results more instructive.

2. Effect of pulse injection on fracture propagation

2.1 Dynamic fracture propagation change

After the proppant is transported by the fracturing fluid to the fracture, it begins to accumulate in the fracture due to the influence of gravity. During conventional injection, the proppant gradually reaches an equilibrium height. In the process of pulse injection, the intermittent action of the fluid makes the proppant have no fixed accumulation pattern. Proppant is not uniformly dispersed within the fracture, so traditional equilibrium height calculation models cannot predict proppant distribution patterns. At the same time, due to the non-uniform distribution of proppant, more low-resistance channels will be formed in the propping fracture, thus improving the flow conductivity of the fracture. The non-uniform distribution of proppant in fractures after pulse injection is one of the difficulties in current research. In this paper, the software was used to numerically simulate the distribution pattern of pulse injected proppant. The calculation parameters mainly included injection rate, proppant concentration, pumping parameters, fluid type and proppant type.

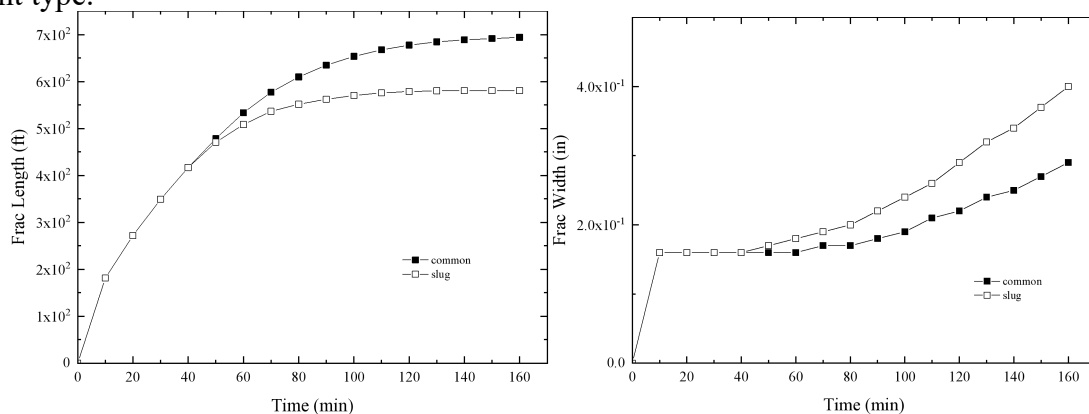


Fig. 1 Dynamic fracture length and width change

According to the dynamic fracture parameters in Fig.1, pulse injection reduces the joint length by about 19.5% and increases the joint width by about 27.5%. According to the numerical simulation results, the fracture volume of pulse injection increases by about 8.7% compared with continuous injection. Comparing the influence of different injection methods on fracture parameters, it can be seen that the fracture growth trend is gentle during pulse injection. Because the injected fracturing fluid displacement is relatively stable, the net fracture pressure changes little. It can be inferred that the type of pumping fluid has little effect on the closing stress.

2.2 Changes of support fracture

The variation of the net fluid pressure during pulse injection is similar to that of conventional injection. It can be seen from the pressure change that pulse injection will cause the net pressure in the fracture to increase continuously. In the process of pulse injection, the extension pressure is relatively large.

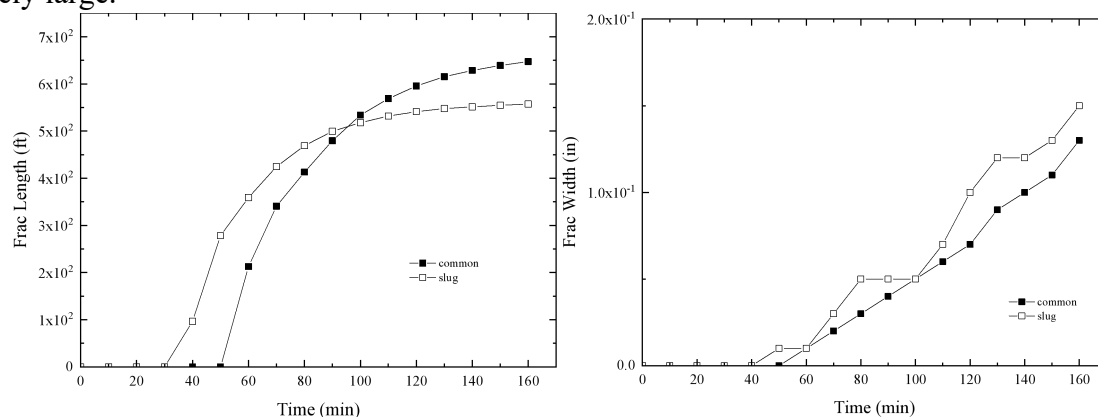


Fig. 2 Proppant fracture length and width change

Compared with the change of propping fracture propagation in Fig.2, the proppant enters the fracture earlier due to the decrease in the amount of pre-fluid. Due to the limitation of dynamic fracture propagation, the propped joint length in the process of pulse injection is larger than that of conventional injection in the early stage, and gradually tends to be flat in the later stage. During the pulse injection process, the width of the support seam changes obviously. With the alternating injection of different types of fracturing fluids, the fracture width fluctuates and increases. Because the change of injection mode affects the change of flow field pressure in fracture, the change of fluid net pressure is used to explain the evolution law of fracture propagation.

3. Proppant distribution in fracture

3.1 Changes in distribution and conductivity

The quasi-three-dimensional proppant distribution pattern shows that proppant clusters formed during pulse injection can create bridging within the fracture. The simulation results are shown in the Fig. 3.

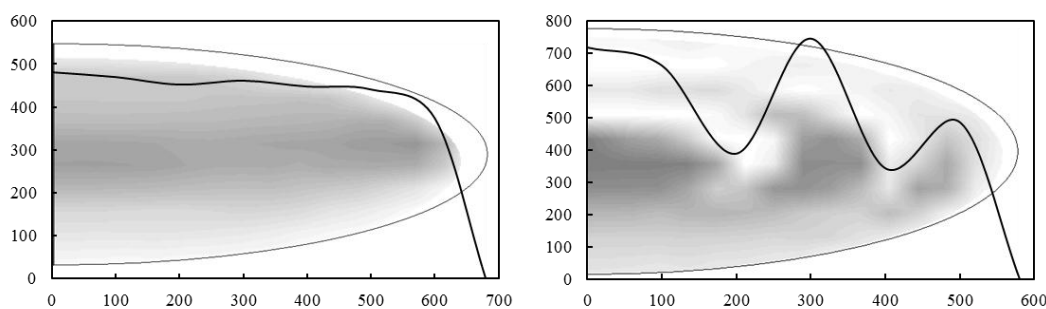


Fig. 3 Proppant concentration distribution in fracture

By comparing the effects of different injection methods on the proppant distribution, it can be seen that the proppant formed a ripple distribution in the fracture after pulse injection. The proppant is evenly distributed after being carried continuously into the fracture, and the proppant is tightly packed, so the space between particles is small. The proppant is not evenly distributed when pulsed into the fracture, thus creating a large number of voids in different areas and improving the fracture conductivity.

3.2 Distribution type in fracture

In the conventional fracturing process, proppant concentration is typically incrementally raised to achieve a consistent propping seam width. In pulse injection, the proppant concentration trend within the sand-carrying fluid pumping stage remains steady, with no proppant injection observed in the intermediate upper fluid pumping stage. Proppant dosage and sand ratio calculation should be conducted in conjunction with pumping parameters to assess proppant distribution patterns within fractures.

Drawing from the mechanism analysis of the injection model, it becomes evident that the distinction between pulse injection and conventional injection primarily lies in the stage of injecting the sand carrier fluid. Consequently, during the design of pumping parameters, the quantity of pre-fluid and the end-displacement body fluid are typically maintained unaltered. To attain enhanced construction outcomes, it is imperative, on one hand, to enhance the transmission efficiency of the fracturing fluid and, on the other hand, to optimize the sequence of construction pumps.

4. Summary

Various injection methods primarily influence the alteration of proppant concentration, and the pattern of flow conductivity alteration essentially aligns with the trend of proppant concentration. Under the influence of proppant concentration during conventional injection, the distribution of the sand bank appears more uniform, and fracture parameters undergo a regular change. Conversely, the fluctuation in fracture parameters during pulse injection stems from variations in proppant concentration as well as injection flow rate.

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