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# Optimal Design of Hydraulic Fracturing for Deep Volcanic Reservoir in Zhungeer Basin

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**Abstract.** Deep volcanic reservoir in Xinjiang Zhungeer basin is buried over 4000m, the elastic modulus of reservoir rocks is high, hence it is difficult to initiate hydraulic fracture during fracturing operation; fracturing fluid filtration is serious and hard to be controlled due to the massive natural fractures in reservoir. Because of the serious heterogeneity along both horizontal and vertical direction, the optimum targets of design fracturing for different well layers are not the same. 4 out of 12 fracturing wells have not achieved the target amount of proppant. Ultimately, fracturing success rate is low and the production increase after fracturing shows a big difference among different wells. In order to improve the success rate and efficiency of deep volcanic reservoir fracturing, based on the analysis of the difficulties in previous fracturing operation, combined with the geological characteristics of reservoir, we optimized the key engineering parameters of deep volcanic rock fracturing, including perforation parameters, filtration parameters, fracture parameters and operation parameters. Results of fracturing design optimization bear an important guiding significance for improving the fracturing success rate and efficiency of deep volcanic reservoir in Zhungeer basin, Xinjiang province.

**Keywords**. Volcanic rock, facture fluid, filtration, natural fracture, hydraulic fracturing

## 1 Introduction

Deep volcanic reservoir is characterized by great burial depth and low matrix permeability. It is necessary to apply the hydraulic fracturing to attain an economic production [1]. Meanwhile, due to the volcanic reservoir develop a large number of natural fractures and dissolved pores, which has serious impact on the opening and expansion of hydraulic fractures, the existence and extension of multiple fractures limit the width of the opening hydraulic fracture [2-5], raised the risk of sand plug[6]. At the same time, the distribution of natural fractures complicates the fluid loss mechanism. Fluid filtration is mainly controlled by natural fracture, and the natural fractures network will change the propagating direction of hydraulic fractures, which will distort and intersect with each other, and finally turn into artificial fractures network [7-11]. Consequently, the opening width at hydraulic fracture tip would be severely restrained and the proppant at the fracture tip will form a bridge plug, lead to the failure of fracturing. Therefore, the corresponding fluid-loss-control measures should be taken to improve the success rate of fracturing [12]. According to the characteristics of volcanic rock reservoir, Vermani et al proposed the slug sand schedule, small diameter proppant, high viscosity fracturing fluid and other measures to improve the operation success rate of volcanic rocks fracturing [13]. Buried depth of volcanic reservoir leads to the high closure stress, and makes the proppant vulnerable under the

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long-term effect of the closure pressure [14], which may impair the hydraulic fracture conductivity. Additionally, the high stress can also lead to the conditions that the volcanic rocks cannot be cracked by existing equipment [15]. Besides the high stress, high temperature usually is an inevitable challenge, , for example, China's Daqing Xujiaweizi fault depression deep volcanic gas reservoir temperature ranged from 120 to 170℃[16], Temperature of deep volcanic reservoir in southern Song Liao basin even reach to 183℃[17], presenting a fundamental challenge to the selection of fracturing fluid.

Jinlong 2 reservoir is a typical deep fault block reservoirs, reservoir buried depth is about 4000m, the development of nearly north-south, east-west nearly two sets of faults, including three near NS faults: Jing201 west fault, Jinglong2 fault and Ke301 fault; seven near EW trending faults: Jing204 south fault, Jing213 south fault, Jing201 north fault, Jing207 south fault, Jing208 south fault, Jing214 south fault and Jing215 north fault. According core physical properties, average porosity of the reservoir is 10.82%, the average permeability is0.43mD, Based on seismic data prestack inversion to predict natural fractures development in northern; the degree of fracture development in southern is relatively weak; the natural fracture width is mainly distributed between the 0.01mm-0.19mm, which are mostly micro-fractures; fracture density is ranged from0.02$m^{-1}$-6.93 $m^{-1}$, the fracture dip angle is generally larger than 45°; the strike of natural fractures is East-West proximately. According to the indoor rock mechanics experiments, the elastic modulus of volcanic rock in Jinlong 2 reservoir is 30152MPa, poisson ratio is 0.186, the direction of maximum principal stress is 118°, with value of 82MPa, the minimum principal stress is 68MPa. In view of the geological characteristics of deep volcanic reservoir in the Zhungeer basin, the key fracturing parameters are optimized based on the analysis of the previous fracturing operation.

## 2 The characteristics of previous fractured well

Based on the fracturing operation of 12 wells in Jiamuhe groups, 4 wells did not complete the target amount of proppant, as is seen in Table 1:

(1) Success rate is low: Jing 218, 219, 203, 212 did not complete the target amount of proppant, which means that fracturing operation of 33.3% wells hasn’t been completed thoroughly.

(2) Efficiency is low: 6 wells are dry layer or water layer after fracturing, which is half the total fractured wells, reflecting that fracturing parameters are required to be further optimized.

Combined with the geological characteristics of volcanic reservoir, the key features of fractured wells in early stage are:

(1) The fracturing effect of gas bearing block is high

Previous fracturing result show that fracturing effect better in two gas bearing fault blocks located in the high position of structure, such as Jing215 wells, Ke301 well(Jing214 fault block), Jing213 well and Jing201 wells(Jing201 fault block).

(2) The operational efficiency at edge and bottom of the reservoir is low

The early fracturing is inefficient for the Jing216 and the Jing203 wells located at the edge of the fault block; At the same time, the oil test results for the Jing215 well at 3940~3932m, Jing214 at 4210~4205.5m, Jing209 at 4350~4334m, and Jing209 at 4324~4302m are either dry layer or water layer.

(3) The well fracturing effect in natural fracture development zone is good

The fracturing efficiency and stimulation effect of wells that located in Jing208 fault, center part of the Jing202 fault and Jing209 fault where developed with natural fractures is preferable.

(4) The fault’s influence on reconstruction is significant

Faults would not only dampen the fracturing effect, but also decrease the fracturing success rate, Jing212 well may be the typical unsuccessful well which is affected by the fault. Fault may change the circumferential stress distribution around wellbore, then alter the extension of fracture morphology and fracture mode, and finally directly affect the effectiveness of the fracturing design and operation.

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(5) The success of fracturing is a prerequisite to fracturing effect

Table 1. Fracturing construction and post production data of deep volcanic reservoir.

| Well | Well depth | Rate | Sand | Pad | Fluid | Sand ratio | Pressure | Production After fracturing |
|---|---|---|---|---|---|---|---|---|
| | | $m^3$/min | $m^3$ | $m^3$ | $m^4$ | % | MPa | t/d |
| JL2002 | 4275~4286 | 3.5 | 28 | 85.5 | 157.5 | 15.9 | 47-69 | 27.77 |
| JL2006 | 3710~3725 | 2-3.5 | 16 | 90 | 105 | 13.3 | 56-60 | 0.00 |
| Jing203 | 4268~4280 | 2.0-4 | 15 | 148 | 144 | 6.9 | 59-68 | 0.00 |
| Jing 204 | 4205.5~4227 | 3.5-3.8 | 21 | 109.6 | 102.6 | 17.5 | 51-65 | 19.01 |
| Jing 209 | 4334~4350 | 2.7-3.5 | 13 | 52.6 | 80.5 | 13.7 | 69-38 | 0.00 |
| Jing 210 | 3158.5~3161.5 | 3.5 | 11 | 30.5 | 59.5 | 16.8 | 45-52 | 3.18 |
| Jing 212 | 4364~4371 | 3.5 | 10 | 76 | 41 | 19.5 | 44-47 | 12.46 |
| Jing 215 | 3866~3880 | 2-3.5 | 25 | 100 | 115.5 | 19.9 | 21-46 | 13.21 |
| Jing 216 | 4390~4397 | 3.0-4 | 12 | 150 | 135 | 5.9 | 57-66 | 0.00 |
| Jing 218 | 3892~3898 | 4.0-5 | 8 | 148 | 90 | 8 | 55-62 | 0.00 |
| Jing 219 | 4245~4250 | 3.0 | 9.7 | 87.5 | 57.5 | 13.4 | 46-65 | 29.94 |
| Jing 220 | 4278~4298 | 2.5-4 | 20 | 200 | 196 | 7.14 | 44-64 | 0.00 |

Figure 1 shows a comparison of the injection proppant, sand ratio and production of fractured wells. Among the 4 wells, JL2002, J203, J215 and J220 with injection proppant amount over 20$m^3$, only J220 is ineffective with a relatively low sand ratio—7.14%. It suggests that a large amount of proppant being injected by efficient sand ratio would improve the efficiency of fracturing. For the 6 ineffective wells, which J203, J216, J218 and J220 four wells sand ratio is 10% or less (J203, J216 and J218 produced water in oil test, J220 is non-productive at all), inefficient sand ratio may directly result in ineffective fracturing. Therefore, both fracture conductivity and propped fracture length play an important role in a successful fracturing operation,

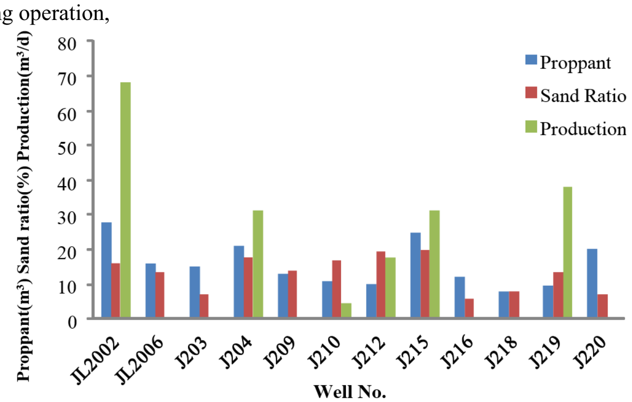


**Fig. 1.** Relationship among proppant amount, sand ratio and fractured well production

Previous fracturing practice and reservoir characteristics determine that the key factor to achieve the fracturing effect of volcanic reservoir is the sand concentration and the length of the hydraulic fracture, the fracturing filtration and the expansion of multi fractures needs be controlled to optimize fracturing effect. The primary guarantees for successful fracturing operation include avoiding excessive extension of multi fractures, as well as reducing the fracturing fluid filtration. The problem of the low success rate and low efficiency need to be solved by optimization design of fracturing parameters. It is difficult to control the expansion and extension of the multi fractures, which is essential part of the design for critical fracturing parameters.

## 3 Filtration control design

When the fracture width is larger than the diameter of proppant, proppant could move unrestrictedly in the fracture without forming effective blockage to control the fracture fluid loss. According to 3 times of particle diameter proppant access criterion, the fracture width should be greater than $2.5d_{prop}$. By using 70 / 140, 40 / 70, 20 / 40 mesh sand plug schedules to control fluid loss, the minimum fracture width to form a blockage is shown in Table 2.

Table 2. The minimum fracture width for different proppant to enter.

| Proppant mesh | Proppant diameter (mm) | Minimum fracture width for different concentration proppant to enter (mm) | | |
|---|---|---|---|---|
| | | 5% | 10% | >25% |
| 70/140 | 0.106~0.212 | 0.29 | 0.36 | 0.636 |
| 40/70 | 0.212~0.425 | 0.58 | 0.73 | 1.275 |
| 20/40 | 0.425~0.85 | 1.15 | 1.45 | 2.55 |

The low concentration proppant cannot control filtration dominated by fissured with over 0.36mm width, while the low concentration medium sand can form a bridge within 1.45mm fractures, but it is high permeability medium cannot reduce the filtration effectively. In most of the fractures with 0.4-1.5mm width, small diameter particles of 100 mesh cannot form an effective blockage, meanwhile, large diameter particles of 20/40 mesh can form a blockage, and its permeability is too high to control the fluid filtration. In order control the fluid loss in open fractures, a dualistic proppant scheme has been proposed— using mixed proppant with different diameters to fill fractures, large proppant for fracture bridging and small proppant for fluid loss control.

Because it is difficult for large proppant to enter the closed natural fractures, conventional filtrate reducer can be used to control the filtration, the commonly used filtration reducer contains silica and clay, but the defects of this kind of material is that when it is get into reservoir it might permanently block some pore channels. In order to address this problem, the JL-1 filter should be selected specifically. Table 3 is the experiment result of filtrate loss control by JL-1.When increase the dosage of JL-1 by 1%, the liquid filtrating time is delayed by 15min, and the wall building filtration coefficient was decreased by nearly 1/2; when increase the dosage of JL-1 by 2%, the wall building filtration coefficient decrease even more. It implies that JL-1 in fracturing fluid has a significant effect on reducing the filtration.

Table 3. JL-1 filtrate loss reducer.

| Item | Total filtration (ml) | C ($m/min^{1/2}$) | Experimental phenomenon |
|---|---|---|---|
| Blank sample | 12.5 | $8.5\times10^{-4}$ | After pressure filtrate filter out soon |
| 1%JL-1 | 7.2 | $4.6\times10^{-4}$ | Filter out 15 min later |
| 2%JL-1 | 6.0 | $3.5\times10^{-4}$ | Filter out 30 min later |

In order to analyze the effect of JL-1 on core permeability. Damage to core permeability in water based gel fracturing fluid is analyzed by using artificial core, result is shown in Table 4.

Table 4. The effect of JL-1 on core permeability.

| JL1 concentration | Core quantity | $K_g$ ($10^{-3}\mu m^3$) | $K_{oil}$ ($10^{-3}\mu m^3$) | Total filtration | Damage rate |
|---|---|---|---|---|---|

| (%) | | | | (ml) | (%) |
|---|---|---|---|---|---|
| 0 | 3 | 9.7-25.6 | 16.18 | 3.62 | 16.8 |
| 2 | 4 | 10.1-25.2 | 16.64 | 2.36 | 15.2 |

As is seen from the above table, the damage effect of the gel fracturing fluid with 2% filtrate reducers concentration is equivalent to that without filtrate reducers. It shows that the impact of the filtrate reducers on formation damage is negligible.

During fracturing operation, the natural fracture opening width would be more than 1-3mm, 20/40 mesh and 100 mesh proppants are simultaneously used to control the fluid loss in multiple fractures. Based on the fluid-loss-control principle of naturally fractured reservoir, in addition to applying proppant slug in pre-pad fluid stage, employing dualistic proppant scheme is also an efficient method to reduce fluid loss in multiple fractures.

Table 5. Pre-pad schedule with proppant slugs for multi - fracture fluid loss control.

| Equivalent fracture width（mm） | Total sand concentration（%） | Middle sand concentration % | Powder sand concentration % | Slug number | Fluid loss additive% |
|---|---|---|---|---|---|
| <0.5 | 3-6 | 0 | 3-6-9 (0.09-0.224mm) | 3 | 1 |
| 0.5-1.0 | 4-10 | 2-4-6(0.45-0.9mm) | 2-4(0.09-0.224mm) | 3 | 1 |
| **1.0-3.0** | **5-10** | **3-6(0.45-0.9mm)** | **3-6-9(0.09-0.224mm)** | **3** | **1.5** |
| >3.0 | 6-15 | 3-6-9(0.45-0.9mm) | 3-6(0.224-0.45mm) | 3 | 1.8 |

## 4 Optimal design of fracturing parameters

**Perforation parameters.** Perforating parameters have a direct impact on the generation and evolution of hydraulic fractures. In order to enhance the operation success rate in volcanic rock reservoir, the length and direction of the perforated section should be optimized. Since the hydraulic fractures initiate and propagate along maximum horizontal principal stress direction, and the maximum principal stress direction of target reservoir is NE113°~NE124°, the perforation azimuth should be controlled to determine the initiating point of hydraulic fracture, so that can not only avoid the hydraulic crack extension along other directions, and can guarantee the hydraulic fracture will not propagate deviously but in a straight line.

Too short perforation interval will result in high perforation friction during fracturing operation; too long perforation interval will lead to multiple fractures extension. The optimization of perforation length can learn from fracturing experience in domestic typical volcanic reservoir, taking the volcanic rock fracturing in DQ oilfield as an example, in order to limit the multiple fractures extension, perforation length is controlled in 5~8m, combined with the practice of previous experience, the perforation length should be controlled within the 10m.

**Fracture parameters.** Propped fracture length and fracture conductivity are the key parameters to influence fracturing effect. There is a strong positive correlation between the dose of the implanted proppant and the long crack length. The relationship between the implemented proppant amount and production after fracturing demonstrates that an adequate propped fracture length is indispensable for fracturing effect. Figure 2 shows that the higher proppant being implemented, the higher the production, therefore, increasing the propped fracture length will improve the effect of volcanic reservoir stimulation.

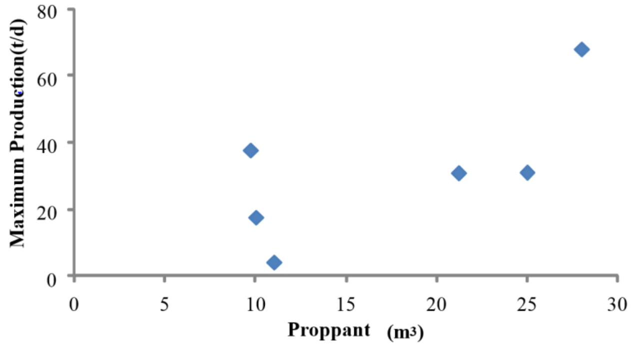


**Fig. 2.** The relationship between proppant amount and oil production after fracturing

There is a strong positive correlation between sand ratio and the conductivity of the propped fracture. The relationship between average sand ratio and production after fracturing demonstrates that an enough fracture conductivity is critical for fracturing effect. However, Figure 3 shows the relationship between the average sand ratio and well production is not obvious, so high fracture conductivity cannot reflect the fracturing effect. On the other hand, it implies that a long hydraulic fracture with appropriate conductivity could maximize the fracturing effect for low permeability volcanic reservoir.

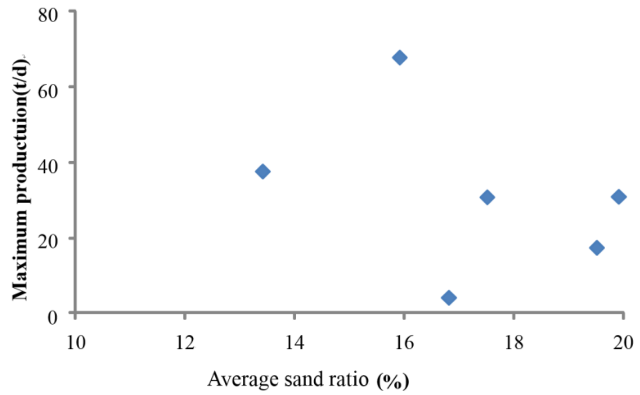


**Fig. 3.** Relationship between average sand ratio and well production.

Figure 4 shows the relationship between hydraulic fracture length and well production, and Fig. 5 shows the relationship between hydraulic fracture conductivity and well production. When the hydraulic fracture half-length exceeds 120m, the increasing length of hydraulic fracture will not contribute to raising well production, so the optimal hydraulic fracture in the reservoir is about 110-120m. Besides, when the conductivity of hydraulic fracture is larger than 25D.cm, the increasing of fracture conductivity dose little contribution to raising well production, so 20-25D·cm is the optimal conductivity to this reservoir. The analysis shows that appropriate conductivity is required for the long fracture in low permeability volcanic reservoir.

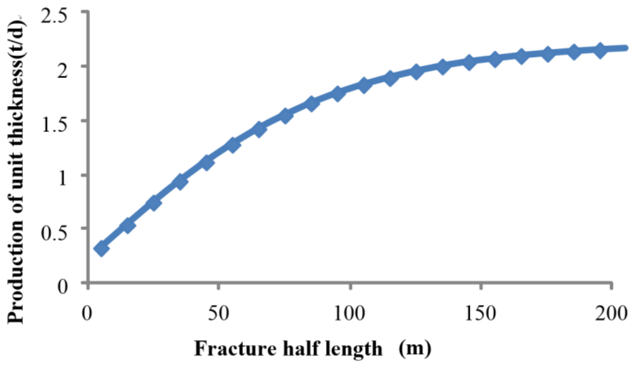


**Fig. 4.** The relationship between hydraulic fracture length and well production.

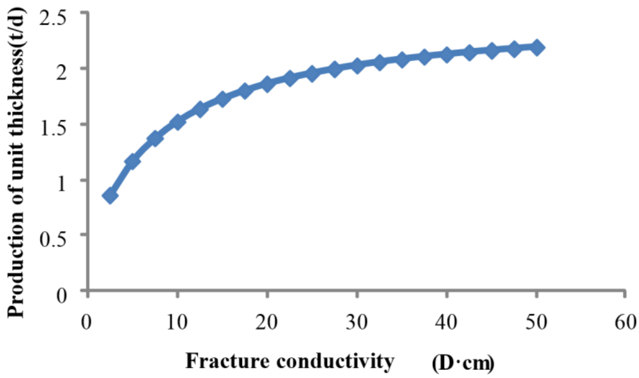


**Fig. 5.** The relationship between hydraulic fracture conductivity and well production.

## 5 Operation parameters

The operation parameters mainly include the pre-pad fluid ratio, sand ratio and pump rate.

**Pre-pad fluid ratio.** The optimization of the fracturing fluid volume is one of the key parameters in fracturing design. It is needed to reduce the amount of the pre-pad fluid to minimize the damage to reservoir. Volcanic reservoir is naturally fractured low permeability reservoir, fluid filtration is a serious problem, in order to reduce the damage of fracturing fluid to the reservoir, we should try to reduce the fluid into well, At the same time, to avoid sand settling to ensure the safety of fracturing, based on hydraulic fracturing fluid characteristics and considering the loss coefficient of reservoir filter is $1\times10^{-3}$m/min$^{0.5}$, when the volume of the liquid volume accounts for about 42% of the total fracturing fluid volume, effective ratio of propped fracture length could reach to 75%, which can meet the requirement of hydraulic fracturing. As a result of adding filtrate reducer in the pre-pad fluid can inhibit the fracturing fluid to flow into reservoir formation, The filtration of the reservoir can be analyzed by a mini fracturing test, so the pre-pad fluid amount could be optimized according to actual filtration, and the pre-pad fluid volume can be reduced to about 40% when the filtration coefficient is reduced to $8\times10^{-4}$m/min$^{0.5}$.

**Sand ratio.** Depending on the simulation of fracture conductivity, the optimal design of propped fracture can be realized when the fracture conductivity reaches 20D.cm. According to the software simulation analysis, assuming that the pre-pad fluid is completely lost at the end of operation, and the requirement of the fracture conductivity for different average sand ratio is shown in Table 6. 20D.cm fracture conductivity demands for 18% of the average sand ratio to achieve design goals, considering the existence of natural fracture in volcanic reservoir, the average sand ratio should be controlled in the range of 15~18% to reduce the risk of sand screen out.

Table 6. Minimum sand concentration/ratio for different fracture conductivities.

| Fracture conductivity (D·cm) | Sand concentration ($kg/m^2$) | Average sand ratio (%) |
|---|---|---|
| 15 | 4.24 | 13 |
| 20 | 5.27 | 18 |
| 25 | 5.91 | 27 |
| 30 | 6.88 | 37 |

**Pump rate.** The optimization of fracturing operation depends on many factors, and the high pump rate is beneficial to increase fracture width. And because of the increase of the injection speed and the decrease of the injection time, both sand settling time and fracturing fluid viscosity breaking are decreased consequently, therefrom, high pump rate could also improve the carrying capacity of fracturing fluid. On the other hand, the high pump rate will result in high net pressure, so that a large number of natural fractures will open, exacerbating the fracturing fluid filtration. From the above, the optimization of the pump rate should not only consider the fluid carrying capacity in volcanic reservoir, but also the control of fluid filtration.

Table 7. the relationship among pump rate, maximum sand ratio and natural fracture state.

| Pump rate ($m^3/min$) | The maximum sand ratio (%) | Natural fracture state |
|---|---|---|
| 1.0 | 17 | Not activated |
| 1.5 | 23 | Not activated |
| 2.0 | 30 | Not activated |
| 2.5 | 35 | Not activated |
| 3.0 | 39 | Not activated |
| 3.5 | 42 | Shear failure |
| 4.0 | 46 | Shear failure |

The critical maximum sand ratio and natural fracture state under different pump rates is shown in Table 7. To meet the 35% of the maximum design sand amount, pump rate at least need to reach 3.0m3/min, meanwhile, when pump rate is lower than 4.0m3/min, natural fractures cannot open, when pump rate is higher than 3.5m3/min shear failure will occur in natural fractures, the filtrate reducer can be used to control fluid filtration and avoid vast fluid loss through massive open natural fractures. From the above, pump rate should be chosen in the range of 3.0~4.0 m3/min.

## 6 Conclusion and cognition

(1) Based on the geological features of deep volcanic reservoir in the Zhungeer basin and the previous fracturing experience, the difficulties of fracturing in deep volcanic reservoir were analyzed, which is mainly reflected in the control of multiple fractures extension and fracturing fluid filtration, and the optimal design of key fracturing parameters.

(2) A comprehensive control methods based on dualistic proppant scheme was proposed to effectively control the fluid filtration in both open and closed fractures, satisfied the requirement of hydraulic fracturing in deep volcanic reservoir. . A pre-pad schedule with proppant slugs was designed to deal with fracturing fluid loss in multiple fractures. These method could dramatically increase the success rate of hydraulic fracturing in volcanic reservoir.

(3) Based on the requirement of controlling the multiple fractures propagation, the perforation parameters were optimized by numerical simulation method. The optimal hydraulic fracture length and conductivity were carried out by using numerical simulation method; Based on the requirement of fracturing operation, the ratio of the pre-pad fluid, sand ratio and pump rate were also optimized, and the results have an important guiding significance for improving the fracturing effect of deep volcanic reservoir.

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