Analysis of Proppant Transportation and Placement Law in Sand Mixing Process

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Abstract: The study of proppant transport and placement is an important step to help optimize the fracturing design, improve the efficiency of oil and gas extraction, and reduce the environmental risk. In this paper, based on the indoor physical simulation experiments of hydraulic sand fracturing in Surig tight gas reservoir, we analyzed the proppant transport and placement law in the sand mixing process by comparing two sand mixing methods, namely, single grain size and combined ceramic grains, with the sand ratio, displacement, viscosity, and proppant type as the main controlling factors. The results show that single particle size can support the fracture near the wellhead zone in the pre-fracturing stage, and the larger the proppant particle size, the larger the sand ratio, the smaller the discharge, the smaller the viscosity of fracturing fluid, the higher the equilibrium height of sand dike formed in the process of transporting in the fracture. Therefore, in the experimental combined ceramic particles, the larger the proportion of large-size proppant is, the better the inflow ability, and the better the inflow ability would be. Considering the flow-conducting ability and economic cost, it is recommended to use the proppant combination ratio of 100/200 (quartz sand):70/140 (ceramic grains):40/70 (ceramic grains) = 1:3:7 for filling. The results of the study can be used to optimize the proppant formulation in Sourig tight gas reservoirs, to reduce the cost of fracturing operations and to improve the efficiency of hydrocarbon recovery in this type of reservoir.

Keywords: Proppant Transport; Fracture Optimization; Sand Mix Placement; Proppant Formulation; Physical Simulation Experiments

1. Introduction

The study of proppant transportation and placement law is an important work in the field of oil and gas development. With the deepening of oil and gas resources exploration and the continuous improvement of development technology, such as the wide application of hydraulic fracturing technology, it has become an urgent need to systematically study the proppant transportation and placement law during sand mixing process.

Proppants play an important role in hydraulic fracturing, as they can fill the fractures and prevent them from reclosing, thus maintaining the permeability of the fractures and promoting the flow of hydrocarbons. However, the selection, transportation and fixation of proppant have a crucial impact on the fracturing effect. Therefore, in-depth understanding of the proppant transport and placement in the formation is important for optimizing the fracturing design, improving the efficiency of oil and gas extraction, and reducing environmental risks.

In this paper, the Sourig tight gas reservoir is selected as the research object, which is a challenging type of gas reservoir with complex geological conditions and difficult extraction. Through indoor physical simulation experiments, the transport and placement law of proppant during sand mixing was thoroughly studied and analyzed with the factors of sand ratio, displacement, viscosity and proppant type as the main control. The results of the study will help provide a scientific basis for the oil and gas recovery in the Sourig tight gas reservoir, and also have a certain reference significance for the development of other similar reservoirs around the world.

2. Principle Guidelines for Experimental Design

2.1 Physical Modeling Design Guidelines

Hydraulic sand fracturing[3] usually consists of the following three processes: (1) pumping fracturing fluid into the formation at a pumping pressure higher than the fracture pressure of the formation, so as to generate and form fractures with certain geometric dimensions in the formation; (2) continuing to inject sand mix with proppant according to a certain design to extend and fill the hydraulic fractures; (3) after stopping the pump, the proppant in the hydraulic fractures gradually settles and supports the fractures, thus forming a channel with a certain inflow capacity[4].

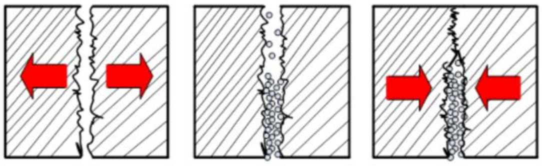

Figure 1. Breakdown of the Hydraulic Fracturing Process

The hydraulic fracture formed by hydraulic fracturing always extends in the direction of the maximum horizontal principal stress, so according to the Carter model, the fracture is assumed to be a rectangular body with fixed seam height and equal seam width, and the flow of sand-carrying fluid in the fracture can be simplified to the flow in a rectangular flat plate, in order to better simulate the proppant transport process in the actual underground fracture, and to ensure the scientific and accurate design, it is necessary to make the physical experimental model and the actual fracture mapping satisfy the similarity criterion. In order to better simulate the proppant transport process in the actual fracture, to ensure the scientific and accurate design, it is necessary to make the physical experimental model and the actual fracture mapping satisfy the similarity criterion, and this equipment satisfies the dynamic similarity[5].

Volumetric fracturing[6] is different from conventional hydraulic fracturing in that the fracture created is more complex, not a simple biplane fracture, as shown in Figure 2. Therefore, the proppant transport characteristics in a single fracture cannot be completely equated with the proppant in the actual formation[7], and it is necessary to further study the proppant transport characteristics under the influence of branching fractures.

Indoor physical modeling is one of the most important methods to study proppant transport in hydraulic fractures. In order to effectively carry out physical modeling experiments, the "complex fracture" is simplified to a "bifurcated fracture" formed by a combination of a main fracture and three levels of branching fracture, and the bifurcated mode fracture type is used to characterize the complex fracture morphology formed by volumetric fracturing of unconventional reservoirs[8]. In order to more realistically approach the actual situation of the fracture, it is necessary to construct a permeable flat plate slit sand transport physical simulation device. The hydraulic fractures formed by hydraulic fracturing are always along the direction of the maximum horizontal principal stress. Therefore, according to the Carter model[9], the fracture is assumed to be a rectangular body with fixed fracture height and equal fracture width, and the flow of sand-carrying fluid in the fracture can be simplified to the flow in a rectangular flat plate. In order to better simulate the process of proppant transport in the actual underground fracture, and to ensure the accuracy of the design, it is necessary to make the physical experimental model satisfy similarity criterion to the actual fracture mapping, and the present device satisfies the dynamic similarity.

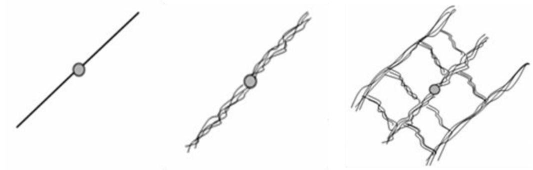

Figure 2. Complex Fracture Structures in Reservoirs

2.2 Physical Model Similarity Principle

From the theoretical basics of fluid mechanics, it can be seen that in the model simulation experiment, in order to ensure that the fluid flow in the indoor model has the same flow law in the reservoir, and to be able to reflect and analyze the actual situation of fluid flow in the reservoir prototype through the results of the model simulation experiment, the model and the prototype must meet the fluid flow similarity. According to the basic theorem of mechanics, there are certain constraints between the length scale, velocity scale, and force scale, and these constraints are the similarity criteria. When all the similarity criteria are satisfied at the same time, it can be ensured that the fluid flow in the model is similar to the actual fluid flow in the formation, and the simulation experiment has practical significance[10]. Due to the limitation of practical conditions, when conducting model simulation experiments, only certain forces that play a major role in the fluid flow (generally simplified to one main force) are considered to make the single similarity criterion of the flow satisfied.

In this experiment, the crack width is kept consistent with the actual crack; the proppant grain size is kept consistent with the actual crack. The scaling simulation criterion is as follows:

A fluid motion characteristic scaling parameter (Re_f) as used to characterize the debris transport flow regime, and the particle settling (Re_p) was used to characterize the particle settling;

$$Re_f = \frac{2\rho_f v_i w}{\mu_f} \tag{1}$$

$$Re_p = \frac{\rho_f v_i d_s}{\mu_f} \tag{2}$$

Shields number (shields, the main controlling factor of sand dike transport) was used to scale the dynamic features:

$$S = \frac{\tau_b}{\left(\rho_s - \rho_f\right) g d_s} \tag{3}$$

formula: v_i —average velocity in cracks，m/s；

ρ_f —fluid density, kg/m3；

ρ_s —density of proppant, kg/m3；

w —wide width, m；

d_s —proppant diameter, mm；

μ_f —fluid power viscosity, mPa·s。

τ_b is the shear stress acting on the top of the sand dike, which can be given by：

$$\tau_b = \frac{1}{8} f_D \rho_f v_i^2 \tag{4}$$

When the dimensionless quantities above the experimental and actual cracks are the same, the simulated and actual cracks satisfy similar dynamics. According to Eqs. (1)-(4), it can be found that if there are the same average velocities in the experimental and actual cracks , then the values of these dimensionless quantities will be the same under the condition that the proppant and fluid used in the experiment are the same as those in the field. In order to obtain the same fluid velocities as in the actual fracture, Eq. (5) was used to design the pumping displacements used in the experiment:

$$\frac{2Q_M}{W_M H_M} = \frac{Q_F}{W_F H_F} \tag{5}$$

formula: Q_M —laboratory pumping displacement, m³/min；

Q_F —Pumping displacement on site, m³/min；

H_M —simulated crack height, m；

H_F —height of real cracks, m；

W_M —simulated crack width, m；

W_F —true crack width, m。

1.3 Simulation Parameterization

In order to simulate the displacement injection in the actual construction, the simulated construction displacement is selected as 3-6m3/min, and the simulated actual fracture slit height is 30m, and the slit width is 0.003m. According to the similarity calculation of the Rayleigh number criterion, the device meets the height of 0.384m, and the slit width is 0.003m. In order to satisfy the similarity of Reynolds number and linear velocity, considering the production cost, experimental site conditions, model size and materials, etc., the experimental displacements of 0.039, 0.051, 0.065, 0.077m3/min are calculated under the same conditions of fracturing fluid density and viscosity. Table 1 shows the values of experimental parameters and dimensionless quantities involved in the design of the scaled-down simulation [11].

Table 1. Comparison of Simulated Parameters of the Device with Actual Parameter Values and Factorless Quantities

Parameter	Prototype (fractured seam)	Model (simulated seam)
Crack height (m)	30	0.384
Main crack half-length (m)	200	5.9
Main crack width (m)	0.003	0.003
Fluid density (kg/m3)	1000	1000
Fluid viscosity (mPa-s)	10-20	10-20
Proppant particle size (mesh)	20/40，40/70	20/40，40/70

Darcy's coefficient of friction	0.04	0.04
Reynolds number of fluid	110-666	110-666
Granular Reynolds number	1.749-212.454	1.749-212.454
Hertz number (math.)	0.0516-47.444	0.0516-47.444
Discharge rate (m^3/min)	8-12	0.076-0.115

3. Experimental Setup Design And Flow

3.1 Structural Design

Based on the principle of simplified structure and easy realization, the structure of the physical simulation device for proppant transport in complex seam networks is determined as control cabinet unit, proppant mixing unit, branch crack flow unit, filtration and circulation unit, in which the proppant mixing unit and branch crack flow unit are the main body and the core of the whole device, and the control cabinet unit and the filtration and circulation unit are the extensions of the device. The schematic diagram of the device is shown in Fig. 3.

The physical results are shown in Fig. 4 and Fig. 5:

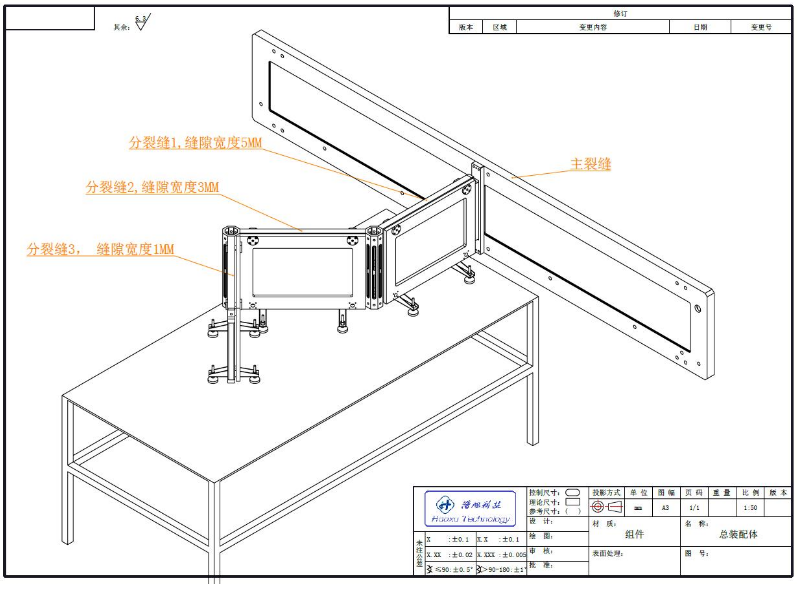

Figure 3. Schematic diagram of Proppant Delivery and Placement Device for Complex Seam Networks

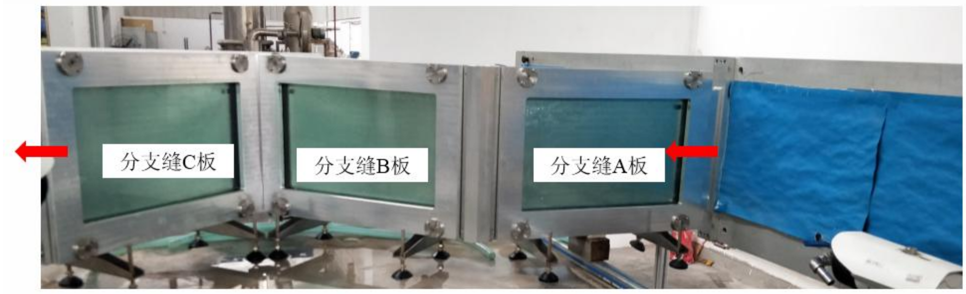

Figure 4. Branch Seam Devices

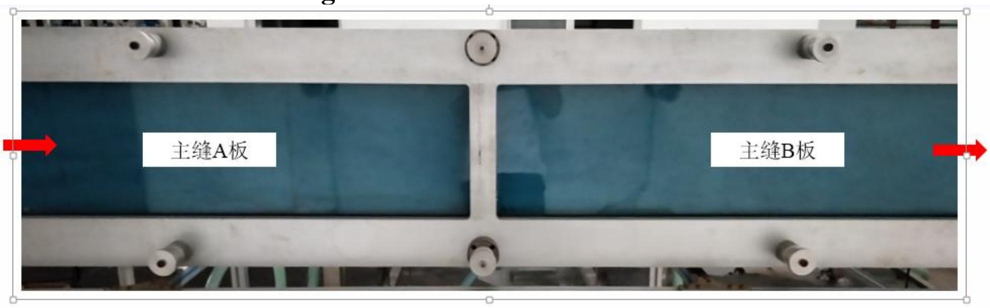

Figure 5. Main Seam Unit

According to the flow process of all kinds of objects in the corresponding pipeline, the flow of the device is briefly described as follows:

Fracturing fluid: the configured fracturing fluid is placed in the water tank, and the required amount of fracturing fluid is calculated according to the sand ratio inputted into the control cabinet, and the quantitative fracturing fluid is pumped to the mixing drum by centrifugal pump, injected at the top, and mixed with the required proppant in the mixing drum.

Proppant: According to the sand ratio inputted into the control cabinet, the weight of the required proppant is calculated and the required proppant is transported to the hopper by the material elevator and then added into the mixing drum through the screw feeder to mix with the fracturing fluid.

Sand-carrying fluid: after mixing well under the stirring of the impeller in the mixing and stirring drum, it is pumped to the visual fracture simulation module through the G-type screw pump to enter the main fracture or branch fracture, and then discharged through the drain valve and recycled to the waste fluid collection tank, which is convenient for the recycling of fracturing fluid and proppant.

3.2 Basic Functional Design

In order to carry out indoor experiments and observe the proppant placement in complex fractures, a proppant transportation and placement device for complex fracture networks is firstly developed. The basic function of the device is to visually and conveniently simulate the proppant transport and placement in complex fractures during the fracturing process under laboratory conditions, and to measure the relevant parameters so as to analyze and study the factors affecting the proppant transport and placement. Based on the analysis of the limitations of the existing simulation device, the main purpose of the design of this experimental device is to improve the proppant sand mixing unit and the branch fracture flow unit, which have the following special functions compared with the previous physical simulation device:

(1) It can precisely control the sand ratio and realize real-time variable sand ratio operation. Through the human-machine interface of the control cabinet, the specified sand ratio can be input, the amount of sand and fracturing fluid can be calculated (ultrasonic liquid level sensors are used to detect the liquid level in the mixing barrel in real time, and the weight of proppant can be measured by the weighing module), and at the same time, impeller stirring is used to realize uniform sand mixing;

(2) Adopting multi-point injection, which can simulate the flow line of sand-carrying fluid and the process of fracture propping while reducing the inlet effect;

(3) Hollow prisms are used to connect five flat plates, which are connected to the visualized crack unit through different faces of the prisms to form multi-angle cracks from 0 to 180°;

(4) The crack simulation module is arranged with a pressure detection unit, which can dynamically monitor the pressure change inside the module, and the maximum stroke of crack opening and closing is 10mm, and the initial opening stroke size can be manually set by human beings, which realizes the adjustable crack width of 0-10mm;

(5) Drainage joints and waste liquid tanks are installed to facilitate the cleaning of simulated cracks, collection of waste liquid and recycling of sand to avoid sand blockage.

3.3 Experimental Preparation and Procedure

The materials prepared for the experiments in this study are mainly quartz sand proppant, ceramic granule proppant, glue breaker, drag reducer, and clear water. The specific material properties are shown in Table 2.

Table 2. Proppant Material Performance Index

Proppant name	Particle Size (mm)	Bulk Density (g/cm3)	Roundness	Sphericity	Crushing Rate (86mPa)
40-70 mesh quartz sand	0.212-0.425	1.485	≥0.9	≥0.9	2.47%<10%
40-70 mesh ceramic granule	0.212-0.425	1.532	≥0.9	≥0.9	3.79%<10%
30-50 mesh ceramic granules	0.355-0.600	1.586	≥0.9	≥0.9	3.62%<10%
20-40 mesh ceramic granules	0.850-0.425	1.586	≥0.9	≥0.9	3.45%<10%

The following experimental procedure was set up according to the selected experimental materials:

(1) Based on the construction information such as the seam width size, pumping displacement, and construction sand ratio of the fracturing joints in the mine construction, calculate the data such as fracturing fluid displacement and sand

ratio in the experiment based on the principles of geometric similarity and Reynolds number similarity, and measure and record the viscosity of the selected fracturing fluid;
(2) Check the sealing of the experimental device and adjust the angle between the branch seam and the main seam to a predetermined angle;
(3) Adjusting the displacement of the experiment to the designed displacement in step (1) through the PLC control system, pumping the fracturing fluid without proppant into the flat fracture to form a circulating loop; said circulating loop means: the fracturing fluid enters the simulated fracture from the entrance of the simulated fracture, enters into the simulated fracture, and exits the simulated fracture through the end of the main fracture and branch fracture, and enters into the fluid pool;
(4) Turning on the variable-speed motor in the proppant sand mixing unit through the PLC control system, adjusting the scraper below the sand storage tank, and starting to add sand at the sand ratio calculated in step (1);
(5) Start timing from the moment the proppant enters the crack until all the prepared liquid is pumped, and record the morphology of the sand dike and related parameters by camera; if there is proppant pumped in the branch crack, it is necessary to record the morphology of the sand dike in the branch crack as well as related parameters;
(6) Stop pumping sand-carrying fracturing fluid into the artificial fracture after the sand dike reaches the equilibrium state;
(7) Flush the artificial fracture with water in large volume, and dry the flushed proppant for the next experiment.
(8) End of the experiment.

3.4 Experimental Program

3.4.1 Single Particle Size Proppant Mixed Sand Placement

In order to study the influence of the main control factors such as proppant type, proppant particle size, displacement, sand ratio, fracturing fluid viscosity and proppant particle size ratio on the fracture proppant transportation law, a 4-factor, 3-level orthogonal experiment was designed as shown in Table 3[12].

Table 3. Single Proppant Delivery Experimental Program

Experiment No.	Sand ratio	Displacement	Viscosity (mpa.s)	Type of proppant
1	15	0.076	50	20/40 mesh ceramic granules
2	15	0.096	70	40/70 mesh ceramic granule
3	15	0.115	60	40/70 mesh quartz sand
4	17.5	0.076	70	40/70 mesh quartz sand
5	17.5	0.096	60	20/40 mesh ceramic granule
6	17.5	0.115	50	40/70 mesh ceramic granules
7	20	0.076	60	40/70 mesh ceramic granule
8	20	0.096	50	40/70 mesh quartz sand
9	20	0.115	70	20/40 mesh ceramic granule

3.4.2 Combined Ceramic and Mixed Sand Placement

Ten groups of transport and placement experiments with different grain sizes of ceramic grains combined proppant were carried out, and the results of sand transport experiments were also characterized by equilibrium height HEQ and leading edge distance LEQ. According to three different grain sizes of ceramic proppant (20/40 mesh, 30/50 mesh, 40/70 mesh), different combinations of ceramic mixed sand placement experiments were designed. The experimental process maintains the same displacement, sand ratio, and fracturing fluid viscosity.[13]

Table 4. Combined Proppant Transport Experimental Program

engine displacement m3/min	sand ratio	Type of proppant	Stickiness mPa·s
0.076	18	20/40(ceramic granule)：30/50(ceramic granule)：40/70 (ceramic granule)=1：2：3	60
0.076	18	20/40(ceramic granule)：30/50(ceramic granule)：40/70 (ceramic granule)=1：3：2	60

0.076	18	20/40(ceramic granule)：30/50(ceramic granule)：40/70 (ceramic granule)=2：1：3	60
0.076	18	20/40(ceramic granule)：30/50(ceramic granule)：40/70 (ceramic granule)=2：3：1	60
0.076	18	20/40(ceramic granule)：30/50(ceramic granule)：40/70 (ceramic granule)=3：1：2	60
0.076	18	20/40(ceramic granule)：30/50(ceramic granule)：40/70 (ceramic granule)=3：2：1	60
0.076	18	20/40(ceramic granule)：30/50(ceramic granule)：40/70 (ceramic granule)=1：2：2	60
0.076	18	20/40(ceramic granule)：30/50(ceramic granule)：40/70 (ceramic granule)=2：1：2	60
0.076	18	20/40(ceramic granule)：30/50(ceramic granule)：40/70 (ceramic granule)=2：2：1	60
0.076	18	20/40(ceramic granule)：30/50(ceramic granule)：40/70 (ceramic granule)=1：1：1	60

4. Experimental Results and Analysis

4.1 Experimental Results of Single Particle Size Proppant Mixed Sand Placement

By obtaining the morphology of the sand dike, the data of 30 sets of experimental results were processed according to the selected characterization parameters [14], and the sand dike characterization parameters are shown in Table 5.

Table 5. Characteristic Parameters of Sandbanks

Experiment Serial number	sand ratio	engine displacement	Stickiness mPa·s	Type of proppant	Balance height (mm)	leading edge distance (cm)
1	15	0.076	50	20/40mesh ceramic granule	110.05	6.54
2	15	0.096	70	40/70 mesh ceramic granule	68.13	10.85
3	15	0.115	60	40/70 mesh quartz sand	56.5	10.91
4	17.5	0.076	70	40/70 mesh quartz sand	88.48	8.38
5	17.5	0.096	60	20/40 mesh ceramic granule	125.32	7.31
6	17.5	0.115	50	40/70 mesh ceramic granule	82.86	10.35
7	20	0.076	60	40/70 mesh ceramic granule	120.43	7.51
8	20	0.096	50	40/70 mesh quartz sand	113.1	10.77
9	20	0.115	70	20/40 mesh ceramic granule	113.24	7.54

The results of the orthogonal experiments were analyzed using the response mean method, and the mean value of each factor at each level was found based on the results of the orthogonal experiments.

A single level of a factor corresponds to all response means:

$$\bar{y} = \frac{1}{4}\sum_{i=1}^{4} y_i \tag{6}$$

According to the plot of the mean of each response against the level, a positive slope of the slash of the response indicator indicates that the response is positively correlated with the indicator, and a negative slope indicates a negative correlation.

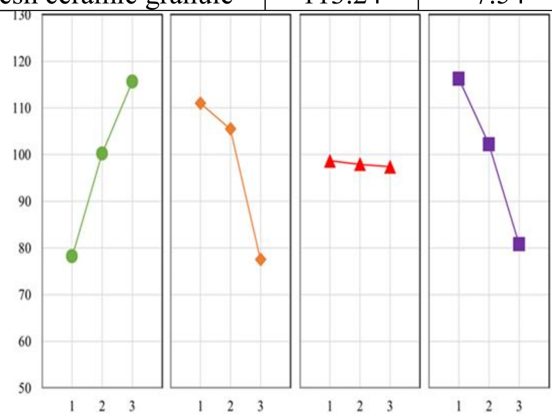

Figure 6. Equilibrium Height Response Mean

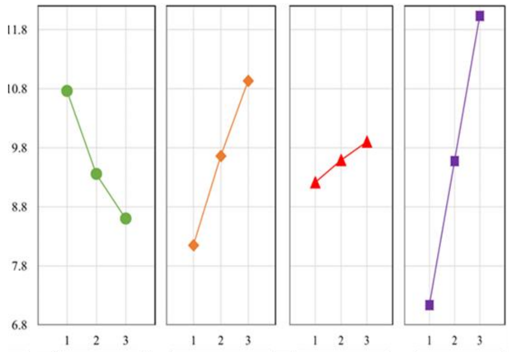

Figure 7. Mean Value of Leading Edge Distance Response

According to the results of response mean ranking, the higher Delta is, the higher the influence of the factor on the index, and the ranking of 1 indicates that the factor is the main controlling factor of the corresponding index, and according to the analysis results, it is considered that the type of proppant is the main controlling factor affecting the morphology of the sand bank.

Equilibrium height: proppant type > sand ratio > discharge > viscosity.

Leading edge distance: proppant type>displacement>sand ratio>viscosity.

Table 6. Balance Height and Leading Edge Distance Ranking Table

norm	parameters	sand ratio	engine displacement(m3/min)	stickiness (mpa·s)	Type of proppant
Balance height	Delta	38.7	29.12	19.75	46.89
	ordered list	2	3	4	1
leading edge distance	Delta	2.16	2.79	0.69	4.89
	ordered list	3	2	4	1

The larger the proppant particle size, the larger the sand ratio, the smaller the displacement, the higher the viscosity, the higher the sand dike equilibrium height, and the smaller the distance between the leading edges of the sand dike, it is more favorable to the extension support of the fracture in the near-wellhead zone, and is not conducive to the proppant transportation to the depth of the fracture.

Under the same grain size, the equilibrium height of sand dike of ceramic grain is higher than that of quartz sand, and the distance between the leading edges of sand dike is smaller than that of quartz sand, which can get better placement effect at the mouth of the fracture.

4.2 Combined Proppant Mixed Sand Placement Experiment Results

Compared with the combination of large-size proppant and small-size proppant, the former can be deposited faster in the cracks, and the closer to the injection end, the greater the amount of deposition, and large-size proppant is conducive to the formation of a larger equilibrium height of the sand embankment and a small distance between the leading edges, but is not conducive to the filling of long cracks.

Different combinations of ceramic grains sand mixing sand embankment laying pattern found that: the same sand ratio, the higher the proportion of large-sized ceramic grains, the higher the equilibrium height of the sand embankment

According to the experimental results, 20/40:30/50:40/70 with the ratio of 3:2:1, 3:1:2, 2:3:1, 2:2:1 and 1:1:1 has better filling effect, and it is recommended to be adopted on site.

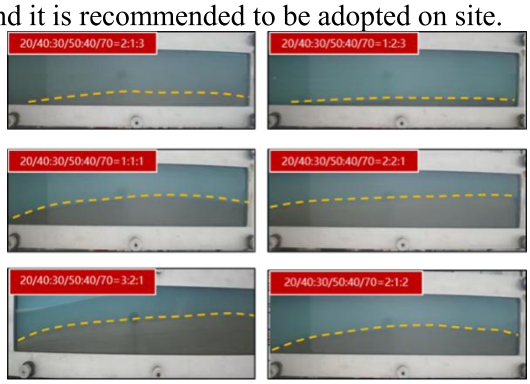

Fig. 8 Combined Proppant Mixed Sand Placement Experimental Results

4. Conclusion

(1) Through indoor physical simulation experiments of hydraulic sand fracturing, the changes of sand dike morphology in fractures with different sand ratios, discharges, viscosities and proppant types of single and combined proppants are described, and the proppant transport and placement laws under different main control factors during sand mixing are clarified, which provide theoretical support for the optimal design of proppant in tight gas reservoirs to improve the recovery rate of hydrocarbons.

(2) In the process of fracture support, the characteristics of proppant have significant

influence on the formation of sand dike. For a single ceramic proppant, the larger the particle size, the larger the sand ratio, the smaller the displacement, and the smaller the viscosity of the fracturing fluid, the higher the equilibrium height of the formed sand dike and the smaller the distance between the leading edges of the sand dike. Therefore, it is recommended to use this option to extend support for fractures in the near-wellhead zone in the pre-fracturing stage. On the contrary, multiple mixed quartz sand proppant shows stronger transportation ability, and the smaller the particle size, the smaller the sand ratio, the larger the displacement, and the higher the viscosity of fracturing fluid, the lower the equilibrium height of sand dike and the larger the distance to the leading edge of sand dike are formed. Therefore, it is recommended to use this program to lay sand dike in the depth of fracture in the late stage of fracturing to increase the effective length of fractured cracks.

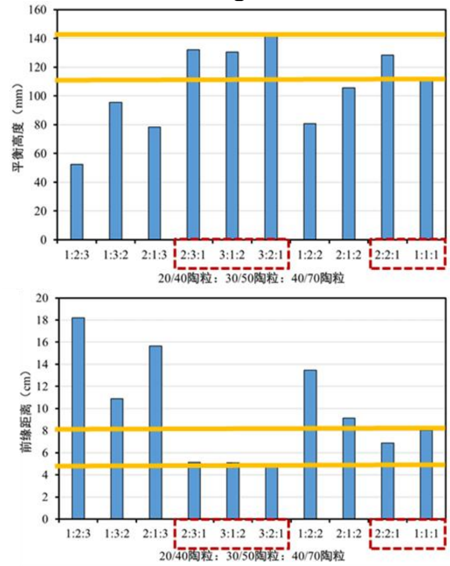

Figure 9. Comparison of Equilibrium Height and Leading Edge Distance of Different Combination Proppants

(3) The particle size of the proppant also has an important influence on its hydraulic conductivity and permeability, and usually, the larger the particle size, the better the hydraulic conductivity and permeability of the ceramic proppant. When using a combination of different types of proppant, the higher the proportion of large particle size proppant, the stronger its flow-conducting ability; and the more the proportion of ceramic grains, the stronger the flow-conducting ability. Taking into account the flow-conducting ability and cost, it is recommended to use the proppant combination ratio of 100/200 (quartz sand):70/140 (ceramic granule):40/70 (ceramic granule) = 1:3:7 for filling.

References

[1] Novotny E J .Proppant Transport[M]. 1977.
[2] Zhang C .Study on overlying strata caving and movement regularity of ascending mining in contiguous seams[J].Coal Science and Technology, 2018.DOI:10.13199/j.cnki.cst.2018.08.001.
[3]Zdunczyk J M .HYDRAULIC FRACTURING SAND[J].Mining Engineering,2020,72(7):56-58.
[4] Scheer D , Class H , Flemisch B .Hydraulic Fracturing[M]. 2021.
[5] Hu Y , Zhao C , Zhao J ,et al.Experimental apparatus and method for simulating transport of sand-carrying fluid in fracturing fractures: US16746926[P]. US10801312B2[2024-03-22].
[6] Qi W , Yun X , Tengfei W ,et al.The revolution of reservoir stimulation:An introduction of volume fracturing[J].Natural Gas Industry, 2011, 31(4):7-6.DOI:10.3787/j.issn.1000-0976.2011.04.002.
[7]Sahai R ,Moghanloo G R .Proppant transport in complex fracture networks – A review[J].Journal of Petroleum Science and Engineering,2019,182106199-106199.
[8]Chengdu University of Technology; Researchers Submit Patent Application, Numerical Simulation And Parameter Optimization Method For Volumetric Fracturing Of Unconventional Dual Medium Reservoir, for Approval (USPTO 20200301043)[J].Journal of Mathematics,2020,2291-.
[9] Gavassino L .Mapping GENERIC Hydrodynamics into Carter’s Multifluid Theory[J].Symmetry,2024,16(1):
[10] A. A C ,A. A A .Regimes of Fluid Displacement from an Anisotropic Formation in the Gravity Field[J].Fluid Dynamics,2024,58(6):1061-1075.
[11] Liu J ,Qu X ,Wang J , et al.Investigating the Influencing Factors of Imbibition of Fracturing Fluids in Tight Reservoirs[J].Processes,2024,12(1):
[12]Chen Y ,Li J ,Song Q , et al.Research on Flow Patterns of Two-Phase Fracturing Fluid in Hydraulic Fracture Considering the Fluid Leak-off.[J].ACS

omega,2024,9(2):2432-2442.
[13]Liu J ,Qu X ,Wang J , et al.Investigating the Influencing Factors of Imbibition of Fracturing Fluids in Tight Reservoirs[J].Processes,2024,12(1):
[14]Xueping Z ,Youquan L ,Lang Z , et al.Study on Matrix Damage and Control Methods of Fracturing Fluid on Tight Sandstone Gas Reservoirs.[J].ACS omega, 2023,8(40): 37461-37470.