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Analysis and Application of Water Control Fracturing Technology in Tight Sandstone Gas Reservoirs

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Abstract

Tight sandstone gas reservoirs have a huge amount of resources, but the complex gas-water relationship in some tight sandstone reservoirs severely limits the effective development of natural gas. Previous studies have developed water control fracturing schemes combining multiple techniques such as multi-stage sanding, nitrogen injection, and artificial barriers, which are beneficial for controlling water production and increasing natural gas yield. This paper analyzes the effectiveness of current water control fracturing technology, examines the impact of fracturing construction parameters, and selects a well in a certain block of the Sulige Gas Field. By improving the pumping stop time, perforation position, and construction parameters of secondary sanding, and optimizing the fracture morphology through a quasi-three-dimensional fracture morphology model, the extension of fracture height is suppressed, resulting in an optimized water control fracturing scheme suitable for the reservoir characteristics of the block.

Keywords

Tight sandstone gas reservoirs; Water control fracturing; Fracturing technology; Construction parameters; Fracture morphology.

1. INTRODUCTION

The Sulige Gas Field is a complex tight sandstone gas reservoir that has been discovered for 20 years since 2001. Research on reservoir geology, engineering, and technology has been continuously carried out with the themes of deepening reservoir understanding and efficient development, making it a model for the development of tight gas reservoirs in China [1]. The well area is located in the western part of the Sulige Gas Field, and the most typical feature of the He 8 gas reservoir is the co-production of gas and water [2]. The reservoir has characteristics of "small pore throats, poor sorting, high displacement pressure, low continuous phase saturation, and small main contributing pathways" in terms of pore structure, and its physical properties are characterized by extremely low porosity and permeability. The co-production of gas and water in the same layer is mainly related to the late-stage uplift of the structure and the heterogeneity of the sand body [3]. With the development of the western part of the Sulige Gas Field, the reservoir properties have deteriorated, and the fracturing effect is significantly influenced by parameters such as the mechanical properties of barrier rocks. Therefore, it is necessary to analyze the effectiveness of current water control fracturing technology and develop an optimized water control fracturing scheme suitable for the reservoir characteristics.

2. WATER CONTROL FRACTURING SUPPORTING TECHNIQUES

Water control fracturing supporting techniques are relatively mature, but they have been less applied in tight sandstone gas reservoirs due to the complexity of gas-water relationships. In

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2013, Cai et al. [4] proposed the concept of diversion fracturing technology, which achieved integration of water control and fracturing, and initial field applications showed promising results. In the same year, He et al. [5] conducted field experiments in the Sulige Gas Field using techniques such as relative permeability modification and variable displacement to control fracture height, and achieved good water control fracturing effects. Zhu et al. [6] used coated sand fracturing technology for water control fracturing in the Pudong Oilfield, reducing the water content by 11%. In 2014, Li Jiarui [7] conducted pilot experiments on artificial barriers and selective water control proppants, which provided guidance for water control fracturing in low-permeability reservoirs. In 2016, Luo Mingliang et al. [8-9] prepared RPM water control fracturing fluids using polysiloxane and MES as the main additives, forming suitable conditions for the formation of nanoscale emulsions for water control in tight gas wells. In 2017, Hao Guixian [10] used hydraulic jet fracturing technology for G82-44-1 well reservoir characteristics, resulting in a 4.7% decrease in water content and a daily oil increase of 7.24 tons, achieving the goal of increased oil production and water control. Yang Zhihao [11] developed software for water control selection in horizontal well fracturing sections of bottom-water reservoirs, and practical examples demonstrated its guiding role in on-site fracturing construction. In 2019, Feng Xingwu [12] studied the influencing factors of artificial fracture height and the characteristics of oil-water relative permeability, forming a process technology for controlling artificial fracture height in thin interlayers. In 2020, Zhao Jun et al. [13] used plugging proppant pack fluid for water control fracturing in fractured tight sandstones in the Sulige Gas Field, resulting in an average daily production increase of around 10% per well.

For water control fracturing supporting techniques applied to gas-water co-production in tight gas reservoirs, there are multiple techniques such as multi-stage sanding, liquid nitrogen injection, and artificial barriers [14].

2.1. Multi-stage Sanding Technique:

The multi-stage sanding technique involves injecting the designed total proppant volume into the formation through several stages of pumping. During the fracturing process, low-rate pumping of pre-flush fluid and slurry is done initially to form a sand barrier. Then, the pumping rate is gradually increased while maintaining the sand barrier, slowly increasing the sand concentration until the reservoir is fully stimulated. This technique effectively controls the extension of fracture height and avoids communication with high-water layers in gas-water co-production sand bodies [15].

2.2. Liquid Nitrogen Injection Technique:

The use of liquid nitrogen energizes and enhances the displacement process during proppant fracturing, compensating for the insufficient energy of reservoir fluid flowback. It significantly improves the flowback rate of low-pressure oil and gas wells, thereby enhancing the fracturing effect [16]. The liquid nitrogen injection technique is often combined with forced closure techniques to calculate the flowback rate of fracturing fluid. The results show that the lower the formation permeability, the longer the closure time of the fracture [17]. In the western part of the Sulige Gas Field, the liquid nitrogen injection technique can be used to improve the flowback rate, optimize the proppant distribution, and create high-conductivity gas-water flow channels.

2.3. Artificial Barrier Technique:

During fracturing operations, if the barrier's blocking capacity is weak, it can lead to fractures crossing the barrier. For example, when the water-bearing layer is close to the production layer, it can cause water production and affect the fracturing effect [18]. By pumping low-viscosity fracturing fluid with high-density quartz sand and gel, a low-permeability artificial barrier is created to inhibit the extension of fractures along the fracture height direction [18-19]. When hydraulic fracturing gas-water co-production reservoirs in tight sandstone formations, using

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support agents with different densities and small particle sizes to control the fracture height extension can effectively increase the stimulated reservoir volume and delay the water breakthrough time in gas wells.

3. ANALYSIS OF THE EFFECTIVENESS OF WATER-CONTROLLED FRACTURING TECHNIQUES

By combining the aforementioned water-controlled fracturing techniques, water-controlled fracturing operations were conducted on the sandstone reservoir interval of Well A, which ranges from 3336m to 3352m. This sandstone interval represents a low-permeability and low-porosity reservoir. According to the interpretation of well logging results, the reservoir is adjacent to a water-bearing layer and does not exhibit any significant barrier, indicating a gas-water co-production scenario.

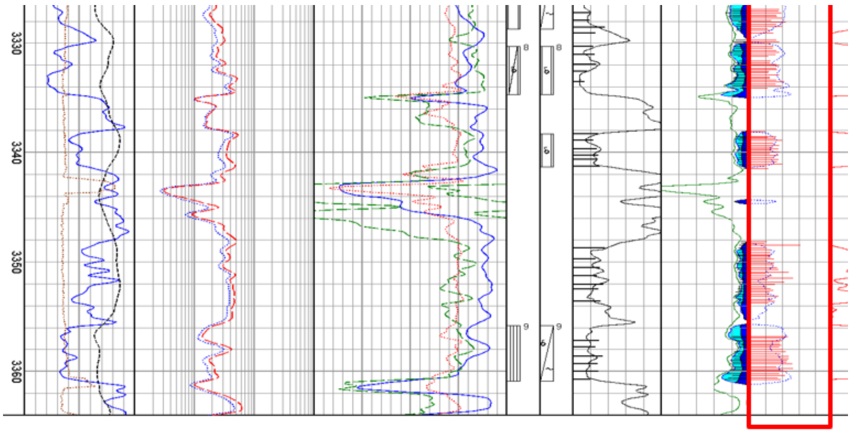

Figure 1. Well A Formation Logging Curve

After hydraulic fracturing, the gas production of Well A has increased. However, the water production remains high, with a daily gas production rate of $1.38\times10^4 m^3/d$ and a daily water production rate of $28.8m^3/d$. The movement of formation water could not be effectively controlled, indicating that hydraulic fracturing has penetrated the water-bearing layer.

To address this issue, numerical simulation of fracture extension was conducted, and the results confirmed that hydraulic fracturing has penetrated the water-bearing layer.

4. OPTIMIZATION OF FRACTURING PROCESS PARAMETERS

Considering the fracturing parameters used in Well A, there is room for improvement in the water-controlled fracturing process. The fracture geometry can be optimized, and the vertical extension of fractures can be suppressed by improving the shut-in time for secondary proppant injection, optimizing the location of the perforations, and adjusting other construction parameters.

A quasi-three-dimensional model is employed to calculate the geometric dimensions of the fractures. The model assumes a homogeneous formation, with the reservoir and cap rock having the same elastic modulus and Poisson's ratio. Fluid flow within the fractures is assumed to be laminar, and the vertical profile of the fractures is elliptical.

The fracture width in the quasi-three-dimensional model is obtained by applying a two-dimensional calculation method along the vertical direction at various points along the length of the fracture. Therefore, the fracture width is a function of net pressure and fracture height [21]:

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$$W_{fe} = \frac{4(1-\nu^2)}{\pi E} H(x) \int_{fl}^{1} \frac{f_2 df_2}{\sqrt{f_2^{\,2} - fl^2}} \int_{0}^{f_2} \frac{p(f_1) df_1}{\sqrt{f_2^{\,2} - fl^2}} \tag{1}$$

The proppant volume has little effect on the variation of fracture length. However, in the multi-stage proppant injection process, the shut-in time significantly influences the hydraulic fracture morphology. With an increase in shut-in time, the hydraulic fracture length shows a decreasing trend followed by an increasing trend. At a shut-in time of 40 minutes, the hydraulic fracture aligns closely with the propped fracture. It can be observed that for different reservoir characteristics, such as the horizontal principal stress of the barrier layer, rock mechanical parameters, reservoir properties, and the position of adjacent water layers, targeted optimization should be carried out.

5. APPLICATION OF OPTIMIZED WATER-CONTROLLED FRACTURING PROCESS

Based on the analysis of factors influencing the water-controlled fracturing process, the sandstone interval at depths of 3389-3403m in Well B was selected for fracturing. The average porosity of the gas-water layer is 13.2%, with an average permeability of 0.27 mD and an average water saturation of 72.3%. There is no apparent barrier between the gas and water layers.

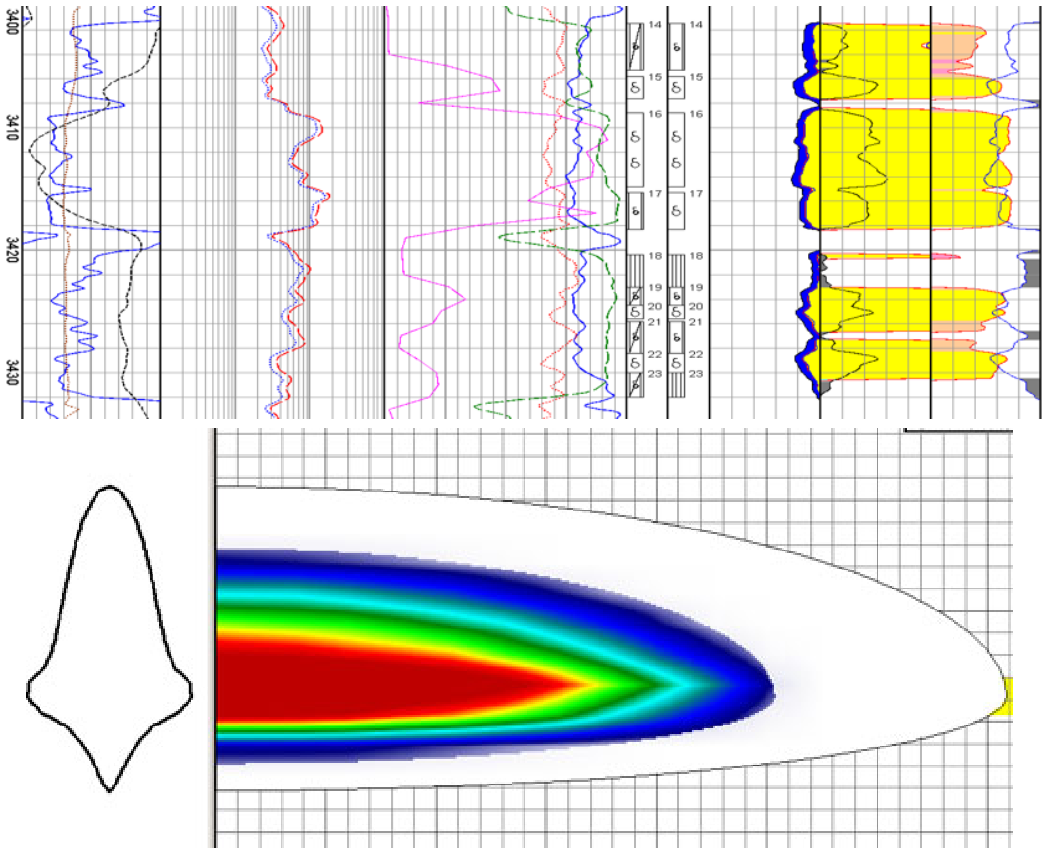

Figure 2. Well B's Production Log and Fracture Morphology

Based on the rock mechanics parameters and physical characteristics, the perforation interval in the upper section of the reservoir was determined to be 3593-3596m. The main

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pumping rate was set at 6 m3/min, with a net fluid volume of 553.8 m3, a proppant volume of 45 m3, and a pre-flush ratio of 37.9%. The shut-in time was set at 50 minutes. After the fracturing operation, the well's daily gas production reached 4.4×10^4 m^3/d, with a daily water production of 5.2 m^3/d. The unobstructed flow rate was measured at 129.78 m^3/d.

6. SUMMARY

In the water-controlled fracturing process of tight sandstone gas reservoirs, the shut-in time and perforation location during the secondary proppant injection significantly affect the water control effectiveness.

Significant differences in water control effectiveness were observed among the two wells that implemented the water-controlled fracturing process in the Sulige West area. Therefore, targeted optimization of water control fracturing schemes should be carried out based on different reservoir characteristics.

After optimizing the water-controlled fracturing scheme for Well B, the recommended construction parameters were as follows: a main pumping rate of 6 m3/min, a net fluid volume of 553.8 m3, a proppant volume of 45 m3, a pre-flush ratio of 37.9%, and a shut-in time of 50 minutes. The post-fracturing production results showed a daily gas production of 4.4×104 m3/d, a daily water production of 5.2 m3/d, and an unobstructed flow rate of 129.78 m3/d.

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