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Analysis and Process Design of Wetting Reversal Agent for Tight Sandstone Gas Reservoirs

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Abstract

Tight sandstone gas reservoirs are strongly water-wet due to the influence of reservoir lithology and physical properties. The high saturation of bound water leads to a decrease in gas phase permeability, which severely affects the productivity of tight gas reservoirs. In order to address this issue, the improvement of rock surface wettability using wetting reversal agents is proposed to adjust the relative permeability curves and ultimately increase the single-well production and recovery efficiency. This study focuses on the Sulige A Block and selects influential factors based on the conclusions of laboratory experiments. The weights of these factors are determined using the grey correlation analysis method. Furthermore, wetting reversal agents compatible with the A Block are carefully chosen. Numerical simulations of the relative permeability curves are conducted, and a micro-fracturing process design is implemented. As a result, a wetting reversal adaptation process is developed specifically for the Sulige A Block, leading to improved single-well productivity and recovery efficiency. These findings provide valuable guidance for the production of the Sulige region in the subsequent stages.

Keywords

Tight sandstone, Gas reservoir, Fracturing process, Wetting reversal agent.

1. INTRODUCTION

Chinese tight gas reservoirs exhibit various characteristics that differ from those in North America, particularly in terms of the diverse abnormal pressure conditions [1-3]. Previous studies by Zhuang et al. [4], Wu et al. [5], and others have investigated the factors influencing the surface properties of tight sandstone gas reservoir cores. They have found that the wettability is primarily influenced by the rock mineral composition and reservoir properties, while gas phase permeability and bound water saturation significantly affect reservoir wettability. Consequently, many researchers have attempted to improve the rock surface wettability by using wetting reversal agents and water-blocking agents. For instance, Jiang et al. [6], Wu et al. [7], Wang et al. [8], and others have established systematic evaluation methods for improving the wettability of tight sand gas reservoirs through injection experiments, contact angle experiments, gas-water phase permeation experiments, and other approaches. In this study, by analyzing the flow characteristics of reservoir core samples and employing the grey correlation degree method, the main factors influencing gas well productivity are identified. Suitable wetting reversal agents are selected, and the design and evaluation of fracturing operations are ultimately completed.

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2. ROCK CORE GAS-WATER PHASE PERMEABILITY CURVE STUDY

2.1. Gas-Water Phase Permeability Curve Experiment

Due to the significantly higher viscosity of the water phase compared to the gas phase, achieving steady-state flow between the two is challenging. Therefore, a non-steady-state method was chosen for the experiment to measure the effective gas phase permeability.

2.2. Experimental Data Analysis

Following the GB/T 28912-2012 standard, 36 sets of relative permeability curves were measured in the experiment. The curves were classified based on porosity, and normalization was conducted for the three categories of relative permeability curves. The resulting permeability curves for different porosities are as follows: The permeability range of Category I curves is 54.57% to 63.62%, significantly higher than the permeability range of Category II and Category III curves. This indicates that Category II and Category III have extremely low gas phase permeability under high water saturation, leading to a sharp decline in well productivity. The iso-permeability point of Category I curves is 0.07, while the iso-permeability points of Category II and Category III are close to 0. This indicates that gas production from individual wells declines rapidly under high water saturation, and if liquid accumulation occurs at the bottom of the well, it will increase the risk of water flooding in gas wells.

3. IDENTIFICATION OF KEY FACTORS CONTROLLING PRODUCTION CAPACITY

(1) Gas-Water Flow Mathematical Model

Mathematical models for gas and water phases in the flow:

Gas phase:

$$\nabla\left(\frac{K\lambda_g\nabla\Phi_g}{B_g}\right)-\frac{q_g}{\rho_{gsc}}=\frac{\partial}{\partial t}\left(\frac{\varnothing S_g}{B_g}\right)$$

Water phase:

$$\nabla\left(\frac{K\lambda_w\nabla\Phi_w}{B_w}\right)-\frac{q_w}{\rho_{wsc}}=\frac{\partial}{\partial t}\left(\frac{\varnothing S_w}{B_w}\right)$$

(2) Analysis of Factors Affecting Production Capacity

By combining the classification of static reservoirs in the Sulige Block, corresponding production capacity models were established to study the impact of different factors on production capacity. The gas-water ratio and cumulative gas production increase in the early production stage with an increase in permeability. At a permeability of 0.08 md, the gas-water ratio gradually increases, while the cumulative gas production tends to level off. This indicates that a higher permeability leads to a higher gas-water ratio and a larger cumulative gas production.

(3) Analysis of Key Factors

Through a comprehensive comparison of multiple methods, this study uses the grey correlation method to identify the key factors. The average values of various results are taken as the final statistical results. The resulting data is as follows:

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Table 1. Weighting Factors of Influencing Factors

Type	Effective Thickness	Absolute Permeability	Effective Porosity	Relative Permeability
Type I: Gas Saturation 45%	0.8423	0.6375	0.8121	0.5814
Type II: Gas Saturation 45%	0.7396	0.6783	0.6765	0.6247
Type III: Gas Saturation 25%	0.6742	0.6652	0.6142	0.5726

Saturation and effective thickness of Class I, II, and III are key controlling factors. The normalized impact factor results show that as the production progresses, the impact of phase permeability on cumulative gas production gradually increases, indicating that improving phase permeability can effectively increase cumulative gas production.

4. OPTIMAL SELECTION OF WETTABILITY REVERSAL AGENT

Based on the evaluation scheme proposed by Wang Jie et al. for wettability reversal agents, this study selects wettability angle, compatibility, and residual resistance factor to optimize wettability reversal agents of different concentrations and types.

(1) Wettability Angle

Wettability reversal agent A and wettability reversal agent B are separately added to the pre-prepared fracturing fluid at concentrations of 0.1%, 0.2%, and 0.5%. The numbered core samples are immersed in the fracturing fluid containing the added wettability reversal agents. After soaking at room temperature and atmospheric pressure for 12 hours, the core samples are taken out and dried for 4 hours, followed by re-measurement of the solid-liquid contact angle. Considering the performance and economic factors of the wettability reversal agents, the 0.2% concentration of wettability reversal agent A is selected as the final choice.

(2) Compatibility

Compatibility experiments are conducted by adding 0.2% concentration of the selected wettability reversal agent A to the formation water and fracturing fluid according to the selected experiment. According to the performance testing standards of water-based fracturing fluids, no significant precipitation is observed, indicating that the 0.2% concentration of wettability reversal agent A meets the compatibility requirements.

(3) Residual Resistance Factor Discrimination

Before conducting displacement experiments, the cores are dried and the permeability and porosity of the cores are measured to obtain the water and gas phase permeabilities at different water saturations. Then, a 10-times volume of the core is displaced using a 0.2% concentration of wettability reversal agent A, and the water and gas phase permeabilities at different water saturations are measured again at various displacement rates. Experimental results show that wettability reversal agent A can effectively improve phase permeability at different water saturations. Therefore, its application in reservoirs with co-production of gas and water can effectively increase gas production and reduce the gas-water ratio.

5. HYDRAULIC FRACTURING PROCESS DESIGN

Combining well log curves and sedimentary facies distribution, FracPT is used for fracturing design. The fracture length is determined to be 146-178m, and the construction parameters are specified. The net fluid volume is 245.38 m3, and the pump rate ranges from 0.6 m3/min to 0.9 m3/min. Based on the single-well production model mentioned earlier, analysis is conducted using a 0.2% concentration of wettability reversal agent A. The final cumulative gas production

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after 10 years increases from 6243×104 m3 to 7951×104 m3, resulting in a 22.6% improvement.

6. CONCLUSION

Considering the static classification of the Sulige Block reservoir, it can be observed that the co-permeable zone and the equal permeability point of the phase permeability curve decrease with the deterioration of reservoir properties. Among them, the gas permeability in the phase permeability curve of Class II and Class III reservoirs sharply decreases with an increase in water saturation.

The influence of reservoir properties and gas-water phase permeability curves on production capacity is studied using the production capacity numerical model. The main controlling factors for single-well production capacity are determined through grey correlation analysis. Adjusting the gas-water phase permeability curves helps improve cumulative gas production and ultimate recovery factor.

Through experiments on wettability angle, compatibility, and residual resistance factor, a concentration of 0.2% wettability reversal agent A is selected, which can enhance single-well production capacity.

By designing the micro-fracturing process, the pump rate and net fluid volume are determined when using wettability reversal agents. The production capacity simulation study shows a 22.6% increase in the final cumulative gas production.

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