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Analysis on Damage Factors of Jilake Reservoir TII, Tarim Basin and the Countermeasures

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Abstract: Jilake Reservoir TII in Tarim Basin, China, is characterized in high clay content, great water sensitivity, small difference between formation pressure and dew point pressure, severe retrograde condensation pollution, water output of gas reservoir and serious water blocking at the low-permeability position of the reservoir, imposing restrictions on the productivity of oil & gas wells. Sensitivity experiments showed that Jilake Reservoir TII was strongly sensitive to water, weakly sensitive to alkali and weakly sensitive to stress. Dynamic core displacement results showed that conventional water-based drilling fluid causes 40% permeability damage. SEM imaging indicated illite/smectite on the rock surface swelled and blocked the primary pore after encountering the drilling fluid. Besides, conventional water-based fracturing fluid caused 70%-90% damage to the permeability, and the SEM results also showed clay minerals swelling after absorbing water from the fracturing fluid. Experiments also showed that that the damage of retrograde condensation was also serious and 15% condensate oil reduced the gas permeability by 30%-60%. Moreover, water blocking damage also occurred to Jilake Reservoir TII, and the damage extent of gas permeability was a function of water saturation. However, the damage can be remitted by adding clay stabilizer and reverse wetting agent into the operating fluid. The laboratory tests indicated that the anti-swelling rate of the clay stabilizer reached 143.8%; the addition of the reverse wetting agent resulted in permeability increase by 3 times for formation water and 1.76 times for condensate oil.

Keywords: Tarim, Triassic, Reservoir Damage Factor, Water Sensitivity, Retrograde Condensation

1. Introduction

Located on the southeast wing of the large buried anticline from the middle section of Tabei Uplift to Lunnan, Jilake Structure is at the transitional zone of the uplift and two depressions, adjacent to Manjia'er Depression in the south, and leaning against Caohu Secondary Depression in the east. Jilake Condensate Gas Reservoir TII on this structure is a sandstone reservoir with high porosity and high permeability. However, the Reservoir is featured by strong heterogeneity, high content of clay mineral, complex oil, gas & water system and gas reservoir type and small difference between formation pressure and dew point pressure. In the initial development stage, the Reservoir had good productivity, but it declined quickly and the Reservoir suffered water production and rapidly rising water content [1]. The gas well always failed to reach the production rate advised by the development program of the reservoir. Therefore, it is necessary to meticulously analyze the causes of the production decrease based on geological and reservoir feature investigations and laboratory experiments of, and then propose and testify the corresponding reservoir protective measures to support efficient development of Jilake Reservoir TII.

There have been many researches on formation damage and the corresponding solutions in the industry. Ali Habibi et al. used MgO Nanofluid to relieve the water shock impairment [1]. F. Salazar et al. used a viscosified blend of chelants and acid as a prepad to hydraulically fracture the water-sensitive formations in Ecuador [3]. Hui Pu et al. studied the condensate blockage in Eagle Ford Gas-Condensate Zone and proposed its remedy [4]. Jiangyu Liu et al. studied the water blocking damage of the tight sandstone in Tarim Basin, China, and proposed a solution of nano fracturing fluid [5]. Mohammed Bashir Abdullahi et al. addressed the liquid loading problem in offshore Niger Delta Gas Condensate Field through dynamic nodal analysis and tubing size optimization based on the investigated operating conditions [6]. Rao Shafin Khan et al. proposed a high-performance acid system to deal with the challenges in depleted, high-temperature, and acid-sensitive sandstone formations [7]. Lufeng Zhang et al. proposed an integrated method to evaluate formation damage resulting from water and alkali sensitivity in Dongping Bedrock Reservoir [8]. However, there are very few reservoirs like Tarim Jilake Reservoir TII, which has a potential of comprehensive damage of water sensitivity, retrograde condensation and water blocking, and thus no single technology can solve the problem. Therefore, fit-for-purpose measures must be studied to relieve the formation damage and productivity decline in Jilake Reservoir TII.

2. Geological and Oil Reservoir Features of Jilake Reservoir TII

The main sand body of Jilake Oil Formation TII is a set of fan-shaped subfacies deposit in the delta front, mainly including the following formation and oil reservoir features: (1) The burial depth is deep, the formation pressure is high (47.4MPa) and the difference between formation pressure and dew point pressure is small (usually 10% lower than the original formation pressure). (2) The lithology is feldspar lithic sandstone and lithic feldspar sandstone, the porosity is mainly primary intergranular pore and intergranular dissolved pore, and the pore-throat combination is mainly composed of large and medium pore – fine-tube throat with comparatively good connectivity. (3) It belongs to a reservoir with high porosity and high permeability (average porosity: 30.3%, average permeability: $407.1\times10^{-3}\mu m^2$), which enjoys good physical properties and relatively strong heterogeneity. (4) The cementation is mainly of porosity type and thin film type. The cementation, mainly argillaceous cementation, is loose. The clay minerals mainly include kaolinite. (5) The nature of reservoir fluid is complex: it is provided with high freezing point, high wax content and high asphalt glue content of crude oil. The total salinity of formation water is high (129,239-201,991mg/L) and the water type is $CaCl_2$. (6) The oil & gas wells suffers quick production decline, water production and rapidly rising water content and black oil in some wells.

3. Sensitivity Damage to Jilake Reservoir TII

3.1. Sensitivity Experiment

Several typical wells at Jilake Reservoir TII were subject to experimental sensitivity analysis according to the industrial standards [9, 10]. The experimental results indicate (Table 1) that Jilake Reservoir TII is strongly sensitive to water, weakly sensitive to alkali and weakly sensitive to stress.

Table 1. *Experimental Sensitivity Results of Jilake Reservoir TII.*

Well No.	Water sensitivity index (%)	Degree of water sensitivity	Alkali sensitivity index (%)	Degree of alkali sensitivity	Stress sensitivity index (%)	Degree of stress sensitivity
XX53-6	61.97	Medium to strong	19.80	Weak	16.00	Weak
XX102-51	32.77	Medium to weak	27.30	Weak	51.90	Medium to strong
XX57-H3-62	73.45	Strong	15.18	Weak	5.00	Weak
XX57-18	78.03	Strong	14.73	Weak	16.70	Weak

3.2. Drilling Fluid Damage Experiment

Dynamic core displacement was made with the drilling fluid at the mine field. The test temperature was 105°C. The core permeability under the steady state was measured with standard saline (base solution) before injecting the drilling fluid, and then, the core permeability under steady state was measured again with base solution after it was stable. The degree of damage is represented with the ratio between the permeability of base solution after damage (K) and the permeability of base solution before damage (K_0). The experimental results (Figure 1) show that the core permeability almost becomes zero after injecting the drilling fluid. After the filter cake is scraped, the permeability recovers to approximately 60% in the initial stage, indicating that the drilling fluid causes 40% permeability damage. According to the SEM image before and after displacement, the illite/smectite formation on the rock surface swells after encountering the drilling fluid, and blocks the primary pore. This is the root cause of drilling fluid damage.

3.3. Fracturing Fluid Damage Experiment

The method similar to the displacement of drilling fluid was used to evaluate the damage of conventional water-based fracturing fluid to the core permeability. The experimental results (Figure 2) show that the water-based fracturing fluid causes severe damage to the core permeability of Jilake Reservoir TII. The damage degree is as high as 70%-90%.

According to the SEM results, the clay minerals swell after absorbing water in the fracturing fluid. As a result, the primary porosity is reduced sharply.

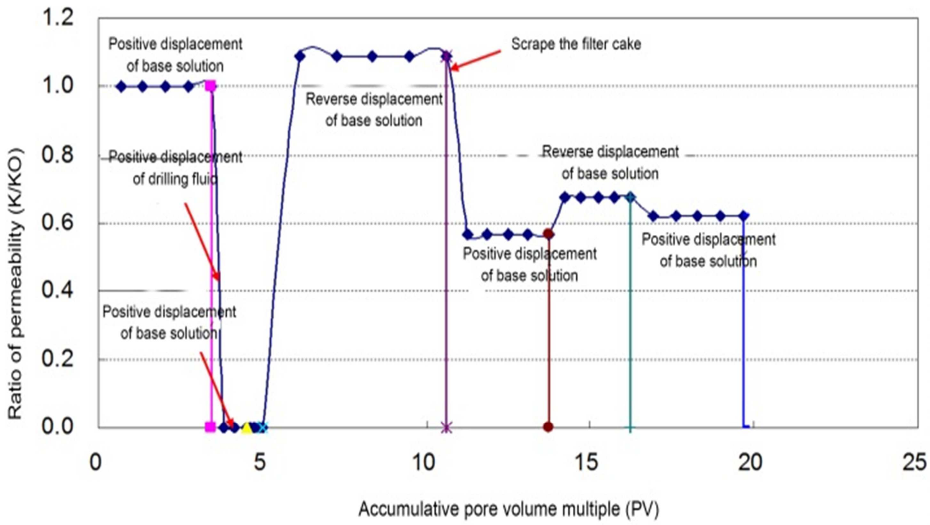

Figure 1. *Drilling Fluid Damage Curve of Well XX102-43-1 (Base Solution: 10% NH_4Cl Solution).*

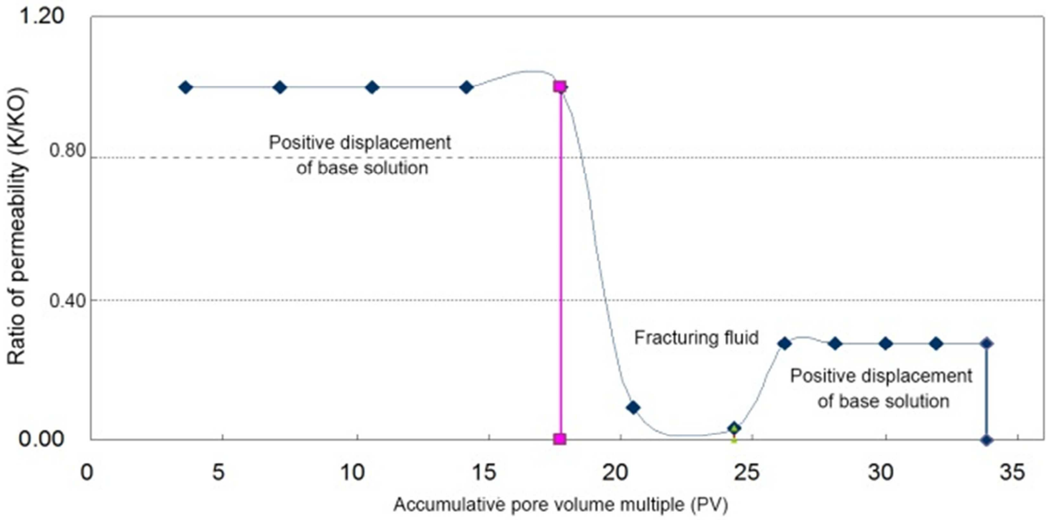

Figure 2. *Fracturing Fluid Damage Curve of Well XX102 (Base Solution: 10% NH_4Cl Solution).*

4. Retrograde Condensation Damage to Jilake Reservoir TII

4.1. Impact of Retrograde Condensation on Production Performance

The production performance of Jilake Oil Formation TII reflects the retrograde condensation damage to the reservoir. Some wells are extensively and severely polluted. In the initial stage of production, Well XX57-H2 was of stable oil & gas yield and produced no water, whose theoretical oil production was consistent with the actual production. After a period of time, however, the well began to produce water, the oil & gas production declined sharply, and the actual oil production was less than the theoretical quantity of condensate oil and the rising gas-oil ratio. It indicates that condensate oil absorbed in the formation and suffered from retrograde condensation pollution. After September 2008, the water, oil & gas production and the gas-oil ratio decreased, indicating that the gas well began to produce black oil and the fluid percolating resistance was further increased. After March 2009, the water yield and the gas-oil ratio went up, and then declined gradually. The oil production continued to decline. In October, the daily oil production was only approximately 1.5t. The theoretical yield of condensate oil was slightly higher than the actual oil production, and gradually trended to be consistent. Thus, it is obvious that the later production of this well is jointly affected by retrograde condensation, water sensitivity and black oil. According to the theoretical calculation results, by the end of November, the retrograde condensation pollution radius of this well reached 1.5m. At present, the formation pressure of this block is lower than the dew point pressure. It begins to separate out condensate oil already. The reservoir is under serious retrograde condensation pollution.

4.2. Retrograde Condensation Damage Experimental Evaluation

The gas permeability under different oil saturation was measured with the core in this block. Based on the test results, the productivity under different contents of condensate oil was calculated with the gas well quasi-stable state productivity calculation model. Then, the damage of retrograde condensation to the permeability and the gas well productivity was evaluated on this basis [11, 12]. Condensate oil from Jilake Reservoir TII causes great damage to the permeability and the productivity: 15% condensate oil will reduce the gas permeability by 30%-60% and the productivity by 20% approximately.

5. Water Blocking Damage to Jilake Reservoir TII

As Jilake Reservoir TII produces water and the water content rises quickly, formation water may retain in some small pores or throats, so as to cause water blocking damage, block the gas seepage channel and reduce the effective gas permeability. Figure 3 shows the displacement experiment made with the core of Jilake Reservoir TII. Quantitative evaluation is made for the degree of water blocking damage through the gas permeability with the same displacement pressure difference and different water saturation [13, 14]. According to the experimental results, the higher core water saturation will result in greater loss on the effective gas permeability. The damage extent of gas permeability is in non-linear relationship with water saturation. Before the water saturation reaches 40%, the descending rate of relative gas permeability is slow relatively. When the water saturation reaches 40%, however, the relative gas permeability loses by approximately 30%. After the water saturation exceeds 40%, the relative gas permeability declines even more violently. It is clear that the invasion of formation water will cause obvious water blocking damage to the seepage channel, and thus influence the actual production of the gas well.

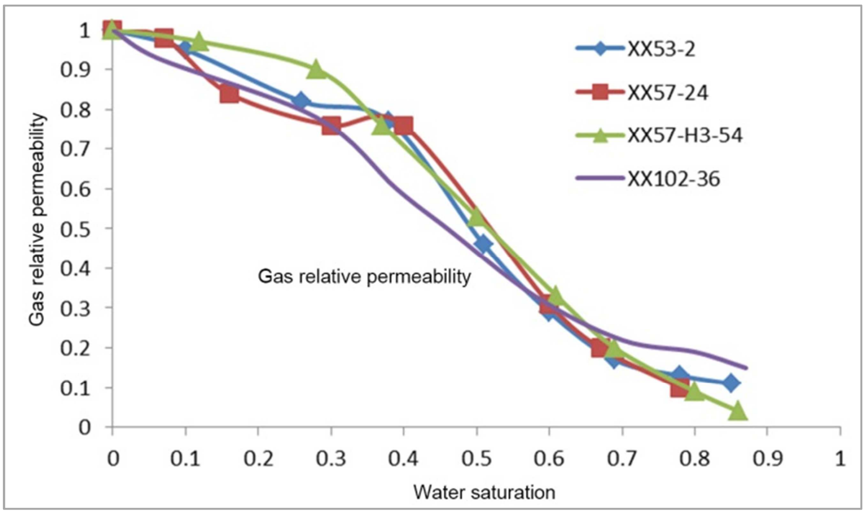

Figure 3. *Relative Gas Permeability under Different Water Saturation.*

6. Countermeasures for Damage to Jilake Reservoir TII

To sum up, Jilake Reservoir TII suffers from serious damage of water sensitivity, water blocking and retrograde condensation. Corresponding measures must be taken for all operating fluids (including drilling fluid, completion fluid and reconstruction fluid) into the well to prevent the water sensitivity damage. The basic approach is to add efficient clay stabilizer to inhibit the clay minerals to swell and migrate. At the same time, it is also necessary to inject certain solvent to relieve the damage of water blocking and retrograde condensation. It is essential for solvent injection to select an efficient reverse wetting agent.

6.1. Clay Stabilizer

According to the experiment, efficient clay stabilizer SA-V has the best adaption to Jilake Reservoir TII. Clay stabilizer SA-V is a small cationic polymer type clay stabilizer. Besides the properties of common cationic polymer clay stabilizers, it also has some special properties: Clay stabilizer SA-V has strong acting force on clay particles. It is uneasy for de-absorption. The double electrode layer on the clay surface is relatively thin. The repulsive force is comparatively small between the particles at the double electrode layer, making it uneasy for the particles to decompose. Furthermore, for fluid cannot destroy it easily, the clay can be stabilized for a long time. Meanwhile, this clay stabilizer also has small molecular weight, uneasy to cause pore and throat blocking [15, 16].

A comparison was made on the interplanar spacing of Ca smectite treated with several clay stabilizers (e.g. KCl, SA-V and COP-SH). According to the comparison results, the interplanar spacing is the minimum for Ca smectite treated with clay stabilizer SA-V. The interplanar spacing is 13.6255 for Ca smectite treated with 3.0% SA-V. The calculated anti-swelling rate is 143.8%, achieving the purpose of complete anti-swelling.

6.2. Reverse Wetting Agent [17]

The injection of efficient reverse wetting agent is one of effective measures for relieving the water blocking and retrograde condensation damage to Jilake Reservoir TII. Its fundamental principle is described as follows: The rock pore and fissure wall surfaces of condensate gas reservoir are always hydrophilic or oleophilic, whose wettability can be changed into neutral wetting by injecting specific reverse wetting agent, thus making remarkable improvement to the liquidity of the fluid on the wall surface of pores or fissures and to the productivity of condensate oil gas reservoir.

According to the experiment, the reverse wetting agent system combining fluorine-containing surfactant with alcohol has the best adaption to Jilake Reservoir TII. Under the formation condition, it can penetrate into the water film or oil film on the rock surface, stripping the adhesive oil film or water film from the surface of pore or fissure. Then, it will absorb on the formation surface through chemical linkage, electrostatic attraction and other acting forces, forming a film of reverse wetting agent with excellent lyophobic and oleophobic properties, and changing the surface wettability of pore or fissure into neutral wetting [9]. At the same time, the carrier fluid of fluorine-containing surfactant is an alcohol system easy to volatile, which is dissolvable in oil and water. Accordingly, it can accelerate liquid evaporation, and relieve the damage of water blocking and retrograde condensation in a better way.

Table 2 shows the changes of liquid permeability before and after injecting the fluorine-containing surfactant tested in the laboratory. It can be seen that after the treating fluid is injected, the permeability of core formation water increases by 3 times (from 1.89mD to 5.57mD), and the permeability of condensate oil increases by 1.76 times (from 2.37mD to 4.18mD). It indicates that this surfactant has good effect for relieving liquid damage.

Table 2. *Changes of Formation Water and Crude Oil Permeability before and after Injecting Fluorine-containing Surfactant.*

	Before injection	**After injection**	**Increase multiple**
Formation water permeability, mD	1.89	5.57	3
Condensate oil permeability, mD	2.37	4.18	1.76

7. Conclusion

Jilake Reservoir TII has a high mineral content of clay, and suffers from serious water sensitivity damage. Conventional water-based drilling fluid causes 40% permeability damage. Conventional water-based fracturing fluid caused 70%-90% the permeability damage.

The damage of retrograde condensation also exists in Jilake Reservoir TII, seriously affecting the productivity of gas well. 15% condensate oil can reduce the gas permeability by 30%-60%.

Jilake Reservoir TII has strong heterogeneity and produces water. Formation water will retain in the small pores and throats, causing the damage of water blocking.

Efficient clay stabilizer SA-V can effectively inhibit the swelling and migration of clay minerals, which can be used to deal with the damage of water sensitivity to Jilake Reservoir TII.

The reverse wetting agent system combining fluorine-containing surfactant with alcohol can effectively relieve the damage of water blocking and retrograde condensation, which has good adaption to Jilake Reservoir TII.

It is also recommended that the future work should be focused on the field trials of the clay stabilizer and the reverse wetting agent, the microscopic and internal mechanisms of their damage relief performance, and the fluid formulae or technologies to deal with the compounded damage of formation sensitivity, water blocking, retrograde condensation, etc.

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