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Research and Application of Deep Profile Control and Flooding Technology in Jurassic Reservoir of WQ Oilfield

Yongquan Han, Xiwei Shen, Dianhao Sun, Bin Wei

No. 9 oil production plant of PetroChina Changqing Oilfield Company postcode: 750006, China

Abstract

The Jurassic reservoir in WQ oilfield in Ordos Basin is the main force of oilfield development and management, with reserves accounting for 24.7% and production accounting for 31.5%. Affected by uneven water drive and high production intensity, bottom water coning, the water drive characteristics are complex, the comprehensive water cut reaches 66.0%, the recovery degree is 6.8%, and the water drive efficiency is low. It is urgent to carry out deep profile control and drive technology research to effectively improve the water injection quality and benefit. On the basis of summarizing the water drive treatment experience of WQ Jurassic reservoir over the years, this paper mainly carries out the technical test and adaptability evaluation of small particle size polymer microspheres and viscoelastic self regulating agent energy supplement technology for the water breakthrough wells with different water drive characteristics and oil-water layer contact relationship in the Jurassic reservoir of WQ Oilfield, and further optimizes the process parameters and adjusts the system formula, It greatly improves the profile control and flooding effect in the effective area of water drive, and provides technical reserves for the treatment of similar reservoirs.

Keywords

Viscoelastic Self Regulating Agent; Polymer Microsphere; Water Drive Efficiency; Monthly Decline.

1. Introduction

Jurassic reservoir in Ordos Basin is a typical low permeability reservoir, during the development of water drive oilfield, due to the existence of formation heterogeneity, water injection advances along the high permeability layer, and the water cut of oil well increases year by year. Profile control of water injection well and water plugging of oil well have become important measures for stabilizing production and increasing production[1]. At present, the commonly used profile control systems are mainly water-soluble polymer gel profile control agents, cross-linked polymer profile control agents, particle profile control agents, precipitation profile control agents, foam plugging agents, resin profile control agents, cement profile control agents, and so on. Polymer microsphere profile control and viscoelastic self regulating agent profile control are two new deep profile control technologies. Polymer microsphere profile control forms elastic microsphere with water absorption and expansion through polymer crosslinking, and uses its migration, plugging, elastic deformation, re migration and re plugging mechanism in reservoir porous media to block and migrate continuously in high permeability zone, so as to realize the effect of step-by-step plugging and deep profile control; Viscoelastic self regulating agent adopts high rheological continuous phase profile control and displacement agent to improve the injectability, salt resistance and stability of low-permeability reservoir. By introducing rigid monomer and strong polar monomer, it has high low shear viscosity when entering the large pores of bottom water, increases the

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displacement resistance of injected water to the bottom water layer, drives the injected water to the upper oil layer, and reduces the high shear viscosity of small pores, Expand the sweep and improve the energy of the upper reservoir. In this paper, the injection parameters of polymer microspheres and viscoelastic self regulating agent in Jurassic reservoir are studied through laboratory experiments, and a large number of field tests are carried out to verify them, so as to provide a basis for the selection of plugging agent injection parameters such as microspheres and viscoelastic self regulating agent for field profile control.

2. Geological Survey of Jurassic Reservoir in WQ Oilfield

2.1. Reservoir Geology

Jurassic reservoir of WQ oilfield is located in the middle of Northern Shaanxi Slope. It is mainly continental fluvial deposit and structural lithologic reservoir. At present, 26 reservoirs have been developed, and the main production horizons are Y9 and Y10. At present, the produced oil-bearing area is 47.9km2, the average reservoir buried depth is * * m, the average effective thickness is 11.0m, the average porosity is 16.31%, and the average permeability is 14.3mD. Produced geological reserves 3091.3×104t.

Edge water and bottom water are generally developed in the reservoir, and the contact relationship is relatively complex. According to the shape of oil-bearing body, there are 16 bottom water massive reservoirs and 10 edge water layered reservoirs (see Table 1).

According to the oil-water contact relationship, the production wells of Jurassic reservoir are divided into three categories. Class I contact wells are production wells in direct contact with oil layer and edge and bottom water, class II contact wells are production wells with thin interlayer between oil layer and bottom water or with a long distance between oil layer and edge water, and class III contact wells are production wells with interlayer between oil layer and bottom water greater than 2.0m or without bottom water. Among them, bottom water massive reservoirs are mainly class I and II wells, accounting for 76.5%, and edge water layered reservoirs are mainly class II and III wells, accounting for 71.5%.

Table 1. Statistics of different oil-water contact relations in WQ Jurassic reservoir

Bottom water reservoir	category	Class I	Class II	Class III
	Reservoir (PCs.)	8	3	5
	Number of wells	234	96	101
Edge water reservoir	category	Class I	Class II	Class III
	Reservoir (PCs.)	2	4	4
	Number of wells	89	119	105

2.2. Development Status

The annual oil output of Jurassic reservoir in WQ oilfield is 36.2×104t, 623 oil wells have been opened, the daily oil production level is 987t, the single well productivity is 1.58t/d, the comprehensive water cut is 66.0%, the recovery degree is 18.6%, the oil production rate is 1.2%, 142 water wells have been opened, the daily water injection of a single well is 15m3, the monthly injection production ratio is 0.6, and the cumulative injection production ratio is 0.7.

3. Main Problems in Water Drive Development

3.1. The Whole Reservoir is in the Stage of High Water Cut Development

Jurassic reservoirs in WQ oilfield have small scale, developed edge and bottom water, and the comprehensive water cut is 66.0%, which is in the stage of high water cut development. The

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comprehensive water cut of 16 reservoirs exceeds 60%, and the technical countermeasures for reservoir development need to be further optimized; At the same time, there are 116 oil wells with less than 10 wells and single well points, with a daily oil output of 189t, accounting for 16.0% of the output of Jurassic reservoir. It is difficult to improve the well pattern.

3.2. With the Increase of Recovery Degree, the Water Cut Increases Year by Year

At present, the reservoir is in the stage of high water cut development, and the water cut increases rapidly. For every 1% of geological reserves, the water cut increases by 2.2%, and the average lifting speed of oil-water interface is 0.24m/year. In 2020, affected by the increase of recovery degree, the water cut will increase by 5, affecting the production capacity of 3t/d, which is manifested in the rise of water content wave, and the change of liquid level and salt content is not obvious.

3.3. The Plane Heterogeneity is Strong, the Injected Water Rushes Along the High Permeability Zone, and the Water Cut Rises

On the plane, the injected water is easy to rush along the main direction of the sand body, resulting in water breakthrough in the oil well; On the profile, the problems of water absorption along the perforated section and peak water absorption are still prominent. Through the measures of microsphere profile control, hole supplement and profile control, the utilization degree of water drive is from 54.7%↑57.1%, but the uniform water absorption ratio is still 56.5%.

3.4. The Treatment Effect of Conventional Profile Control System is Poor

The Jurassic reservoir has carried out conventional profile control for 24 wells, 6 types of experimental profile control systems, and 8 comparable wells. The average water absorption thickness of a single well is 4.9m↑5.2m. There are great differences among different layers, and the improvement of water absorption profile is not obvious on the whole; There are 89 corresponding oil wells. Excluding measures, casing damage and other factors, 64 wells can be analyzed. The decline rate is 2.0%↓1.8% in 7 months before and after profile control, and the water cut rise rate is 0.33↑0.49. The water control effect is not obvious.

4. Research and Application of Deep Profile Control and Flooding Technology

4.1. Deep Profile Control and Flooding Treatment Ideas

By analyzing the treatment system and implementation effect over the years, according to different water drive characteristics, water breakthrough types, reservoir physical properties and other characteristics of WQ Jurassic reservoir, carry out deep profile control and flooding treatment, improve water drive efficiency, control water cut rise and reduce reservoir decline.

First, the displacement system has been preliminarily established, water drive has been effective, and the oil reservoirs with increased water content in the well cluster, such as P37-58 and W286, are basically in the middle water cut development stage. The microsphere deep profile control and flooding technology is mainly used to improve the injection performance with small particle size (100-300nm), improve the deep migration performance with low concentration (≤0.3%), and enhance the retention of microsphere with small injection displacement, The principle of increasing the specific surface of small particle size microspheres is used to reduce the water flow velocity and expand the swept volume.

Second, the increase of water cut in oil wells is mainly affected by the dual factors of water drive effect in the early stage and high fluid production intensity, such as W135Y7, Y10 and other reservoirs, which are basically in the stage of high water cut. Viscoelastic self regulating agent

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energy supplement technology is mainly used to make use of the shear rheology of linear polymer solution, that is, there is viscosity in large pores (bulk phase) and small pores (mobile phase), Based on the principle of rapid reduction of solution viscosity, the high permeability dominant channel is blocked as a whole, so as to expand the swept volume coefficient, inhibit the bottom water and improve the efficiency of water injection.

4.2. Polymer Microsphere Profile Control and Flooding Technology

4.2.1. Polymer Microsphere Profile Control and Flooding Mechanism and Parameter Selection

Polymer microspheres have agglomeration and adhesion in the hydration process, and there is a phenomenon of hydration particle size classification. After the nano microspheres enter the high permeability layer, the agglomerated large particles are deposited on the pore surface through physical plugging, and the subsequent small particles are retained in the pores, which increases the specific surface area of the rock and reduces its permeability. The initial particle size of nano microspheres is small, it is easier to enter the deep formation, and the overall plugging strength is large. The effect of oil increase and precipitation is obvious in field application.Theoretical basis: Kozeny equation:

$$K = \frac{c\varphi^3}{\tau \cdot S^2}$$

K :Porosity, the ratio of the total volume of small voids in a porous medium to the outer volume of the porous medium.

ϕ : Permeability refers to the amount of permeability of porous media.

c : Wettability, characterization of wettability of porous media to different fluids.

τ : Tortuosity, the ratio of the real flow of fluid through porous media to the linear distance between inlet and outlet.

S :Internal specific surface area, the sum of the surface areas of all small voids in a porous medium per unit volume.

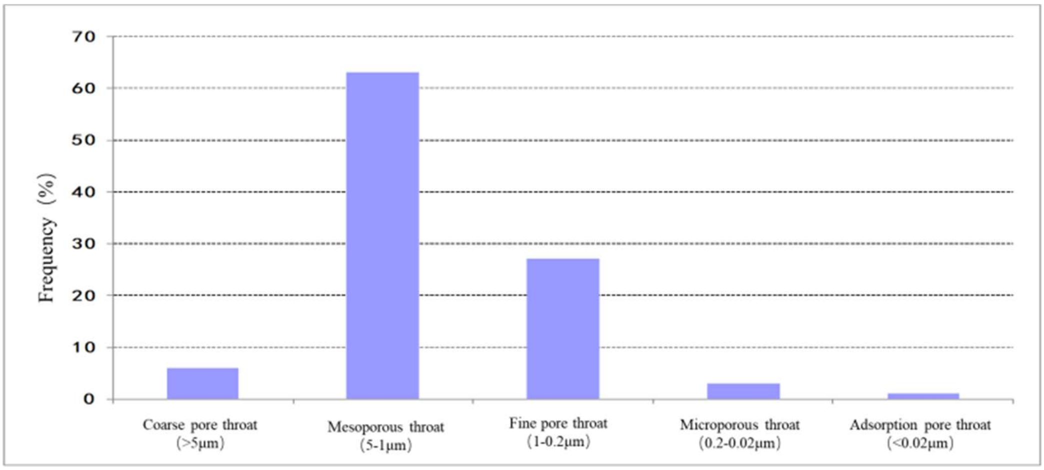

Figure 1. Straightness of throat distribution in Jurassic reservoir

Particle size selection: by comparing the theoretical plugging rate and laboratory plugging rate results of different particle sizes, it is found that the smaller the particle size is, the greater the reduction of permeability is, and the influencing factors of concentration become smaller; If the particle size is less than 800 nm, it conforms to the increasing specific surface plugging theory,

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and if it is greater than 800 nm, it conforms to the pore throat plugging theory; The smaller the particle size is, the easier it is to enter the deep part, increase the specific surface and increase the overall plugging strength.

The throat of Jurassic reservoir is mainly distributed in 5 μm or less (see Figure 1). In order to meet good injectability, the matching particle size should be within 300nm; From the early field application effect, the adaptability of microspheres within 300 nm is significantly better than micron microspheres.

Table 2. Comparison of plugging rates of microspheres with different particle sizes

Particle size	concentration	Injection volume	Water drive permeability before plugging	Water drive permeability after plugging	Plugging rate
	%	PV	mD	mD	%
100nm	0.5	0.3	186	13	92.8
300nm	0.5	0.3	1512	131	91.3
5μm	0.5	0.3	359	133	62.9

Compared with the effect of particle size on plugging rate at the same injection rate, 100 nm microspheres were 5 μm microspheres can be retained more effectively and the plugging rate is higher. The plugging effect of small particle size nano microspheres is better (see table 2).

Concentration selection: the visual model experiment of plane sand filling shows that the injection of low concentration microspheres improves the swept volume greatly, uses less materials for polymer microspheres and has high economy (see table 3).

Experimental conditions: the viscosity of simulated crude oil is 5MPa s, flow rate 0.05ml/min, inject the expanded 100nm polymer microspheres (aged at 55℃ for 10 days), inject water and add blue dye for identification.

Table 3. Comparison of water drive swept volume of two injection processes

Slug concentration	1000μm	5000μm
water flooding0.3PV	9.1%	9.8%
0.6PV(The outlet water content is 100%, and the first ball injection begins)	11.1%	12.9%
Injection 1.2PV	50.9%(0.6PV ball)	31.7%(0.12PV ball)
Injection 1.8PV	63.5%	49.6%(0.12PV ball)
Injection 2.1PV	71.2%	59.2%
Improve the swept volume of water drive	60.1%	46.3%

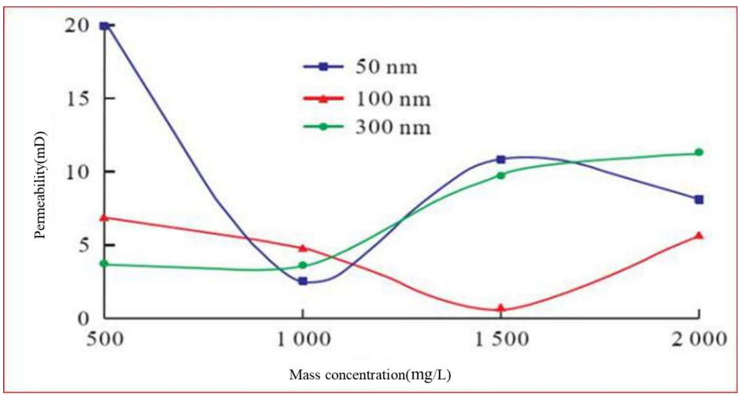

Figure 2. Relationship between polymer microsphere concentration and reservoir permeability

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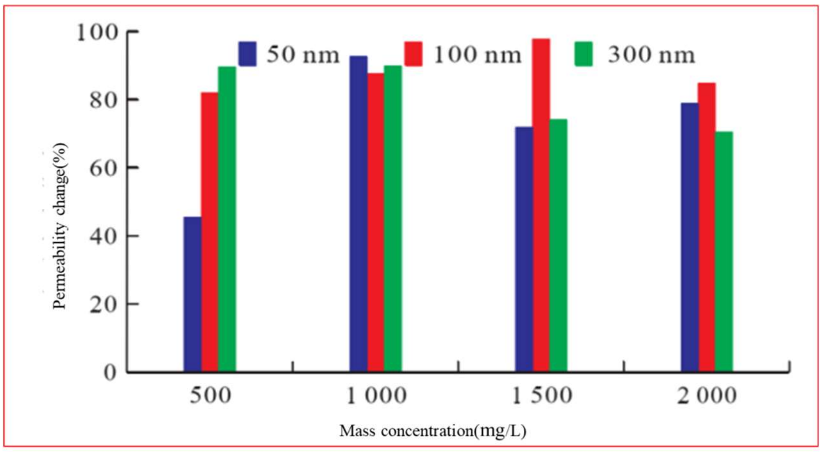

Figure 3. Relationship between polymer microsphere concentration and reservoir permeability

4.2.2. Effect Analysis of Microsphere Profile Control and Flooding in P37-58 Reservoir

Zone P37-58 mainly develops layer Y10 with developed bottom water. It is a typical lithologic structural reservoir. The average oil layer thickness is 7.1m, porosity is 9.75%, permeability is 15.33mD and roar channel is 0.3-5.0 μm. Liquid production strength 0.82m^3/d·m, the degree of water drive production is 52.5%. The main contradiction is that the water injection in the reservoir rushes into the oil well along the sand body belt, and the water breakthrough is obvious.

The daily liquid production of a single well in this area is 3.53m^3/d. The daily energy of a single well is 1.64t/d, the comprehensive water cut is 54.7%, the oil production rate is 1.6%, the recovery degree is 9.0%, the daily water injection of a single well is 12m3, the monthly injection production ratio is 0.7, the porosity is 9.75%, and the roar is 0.3-5.0 μm. The permeability is 15.33mD. Local interlayer is developed, the water breakthrough period is relatively short (21.5 months), and the scouring time of water drive dominant channel is short.

Implementation: microsphere profile control and flooding was carried out for 7 water injection wells with effective water injection in the early stage. The model of microsphere is 100nm, the injection concentration is 1000-1500mg/L, and the dosage of single well is 4.0-5.0t.

Implementation effect:① the injection pressure is 5.3↑5.9↓5.5MPa, in the shape of "several", with good injection performance; ② The profile can be compared with 3 wells, with an average water absorption thickness of 5.2↑7.0m, and the profile is better improved; ③ There are 18 corresponding oil wells (deducting measures and casing damage wells), and there are 6 wells with remarkable results, see efficiency of 33.3%, daily oil production of 32.91↑34.84t/d and comprehensive water cut of 39.1↓28.2%.

4.2.3. Effect Analysis of Microsphere Profile Control and Flooding in X286 Reservoir

The development layer of X286 reservoir is layer Y10 with developed bottom water. It is a typical structural lithologic reservoir with effective thickness of 10.5m, porosity of 16.2%, permeability of 17.9mD and roar channel of 1.0-5.0μm. The liquid production intensity is basically reasonable (0.59m^3/d·m), the degree of water drive production is 62.0%, the overall injection production correspondence of the reservoir is obvious, the interlayer is developed in the west, and the oil-water interlayer is developed in the southeast class I contact, no interlayer.

The single well productivity in this area is 1.73t/d, the comprehensive water cut is 54.6%, the recovery degree is 17.76%, and the oil production rate is 2.3%. Seven wells are opened, the daily injection of single wells is 10m3, the cumulative injection production ratio is 0.60, the water breakthrough period is relatively long (47.9 months), and the scouring time of water drive dominant channel is long.

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Implementation: microsphere profile control and flooding was carried out for 5 wells in 4 water injection wells of the reservoir; Microsphere model: 300nm; Affected by large injection equipment and low daily injection volume, the injection concentration is 1500-2000mg/L; At the same time, increase the dosage of single well (6.0-7.5t dosage of single well) to ensure effective deep plugging.

Implementation effect: ① the injection pressure is basically stable (6.2MPa) and the injection performance is good; ② The profile can be compared with 4 wells, with an average water absorption thickness of 4.3↑4.8m, and the overall profile is not significantly improved; ③ Corresponding to 13 oil wells (deducting measures and casing damage wells), after 3 months of microsphere injection, the comprehensive water cut is 54.5↓51.8%, and the monthly decline is 0.23%; After the validity period of 6 months, the comprehensive water content rises to 56.7%, and the monthly decline is↑1.9%.

4.3. Viscoelastic Self Regulating Agent Energy Supplement and Displacement Control Technology

4.3.1. Profile Control and Drive Mechanism

Based on the shear rheology of linear polymer solution, that is, there is viscosity in macropores (bulk phase), and when entering small pores (mobile phase), due to the increase of shear force, the solution viscosity decreases rapidly. When entering the bottom water layer, the shear in macropores is small and the viscosity is large, increasing the displacement resistance of injected medium to the bottom water layer, so as to expand the swept volume coefficient and improve the reservoir energy, Inhibit bottom water and improve water injection efficiency (see Figure 4 and Figure 5).

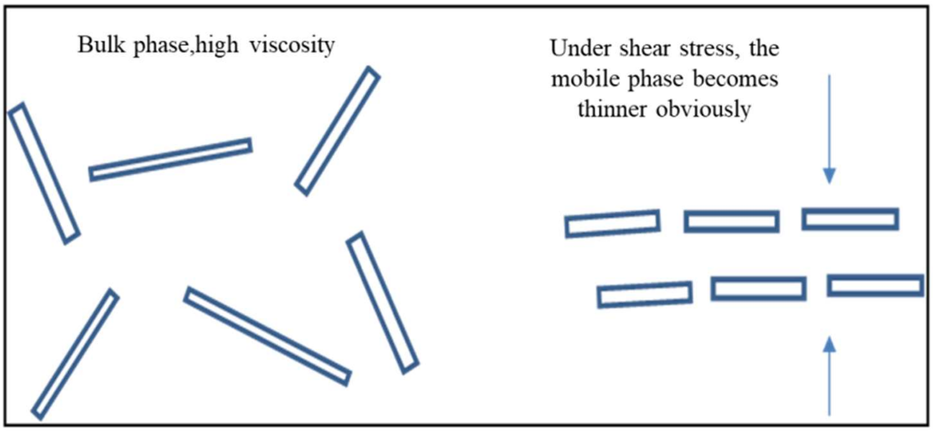

Figure 4. Schematic diagram of action principle of viscoelastic regulator

$$v = \frac{k}{\mu} \cdot \frac{p_e - p_w}{r_e \ln(r_e/r_w)}$$

- The dominant channel has small shear, high viscosity and slow flow rate
- The matrix has large shear, low viscosity and fast flow rate
- Expand sweep and supplement formation energy

Figure 5. Technical idea of viscoelastic self regulating water energy supplement

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Rheology: through indoor evaluation, under high shear stress, the viscosity of viscoelastic self regulating agent solution decreases greatly, and the difference between 0.1% concentration and 0.15% concentration is small. 0.1% concentration injection can be used (see Figure 6).

Viscoelasticity: under the same conditions, the viscoelastic self regulator polymer solution has long tensile fracture time and relaxation time and good viscoelasticity.

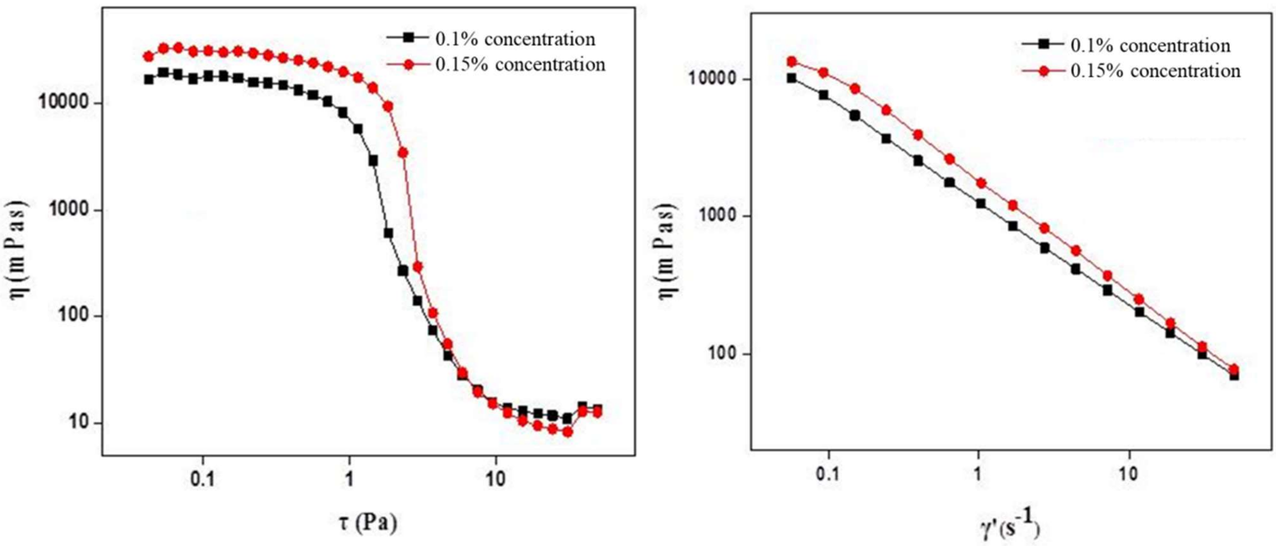

Figure 6. Change of solution viscosity under different shear stress and shear rate

Anti adsorption: on 80 ~ 100 mesh oil sand, the anti adsorption performance of six different polymers was evaluated by multiple adsorption method. The experimental results: the viscosity retention rate of viscoelastic self regulator polymer was the highest (78.0% after 5 adsorption) at the same concentration and the same adsorption times.

4.3.2. Profile Control and Displacement Effect of Viscoelastic Self Regulating Agent in W135Y7 and Y10 Reservoirs

The development layers of the reservoir are Y7 and Y10, with positive rhythmic deposition, active edge and bottom water, few interlayer and good connectivity; The effective thickness is 9.29m, the porosity is 11.2%, the permeability is 25.3mD, the buried depth is 1360m, the single well productivity is 1.45t/d, the comprehensive water cut is 77.7%, and the recovery degree is 46.3%. The overall water injection of the reservoir is effective. The increase of water cut of the oil well is mainly affected by the dual factors of injection water drive and bottom water lift. The water breakthrough cycle is more than 10 years, and the effect of conventional profile control and microsphere profile control drive is poor.

From August 2019 to February 2020, viscoelastic self regulating agent test was carried out for 4 water injection wells, with dosing concentration of 1000mg/L and injection displacement of 1.0-1.5m^3/h. Single well dosing 5t.

Implementation effect: ① the injection pressure rises slowly (8.0↑9.4MPa), and the injection performance is relatively good; ② Corresponding to 16 oil wells (deducting measures and casing damage wells), the liquid volume after injection is basically stable, the comprehensive water cut shows a downward trend of 83.0↓77.7%, the daily oil production is 16.9↑22.7t/d, and the monthly decline is 1.1↓-3.6%. After 12 months, it is still effective.

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5. Conclusion and understanding

1) The interlayer at the oil-water layer interface is developed, and the deep profile control and flooding effect of polymer microspheres in wells with effective water drive in the early stage is remarkable. The injection process is 100nm and 300nm microspheres + 1000-1500mg/L injection concentration, which can effectively improve the contradiction of Jurassic water drive, expand the swept volume and control the rising rate of water cut in the well group.

2) There is no interlayer at the oil-water interface, bottom water development, water cut rise area caused by high production fluid intensity, and microsphere profile control and flooding has no obvious effect. Well selection for next step flooding should avoid such injection production well groups.

3) For the water breakthrough well of Jurassic reservoir affected by bottom water and injection water, viscoelastic self regulating agent can effectively block the high permeability channel, and the effect of the measures is good. In the next step, the test scale can be appropriately expanded.

4) Controlling the injection intensity and injection production ratio and carrying out equal matching injection and displacement control are important conditions for the effectiveness of Jurassic water drive control; The injection production ratio of viscoelastic self regulating agent profile control and flooding well group in WQ old area is controlled within 1.0.

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