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Research on the Technology of Profile Control and Flooding in JY Oilfield to Stabilize Production

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Abstract: *JY oilfield is mainly an ultra-low permeability reservoir with low reservoir permeability. As the permeability decreases, the starting pressure gradient rises sharply, and the establishment of an effective displacement pressure system is slow. The main reservoir has entered the medium water-cut development stage. On the plane, water flooding intrudes along the dominant channels such as fractures and high-permeability strips, resulting in plane contradictions; on the profile, the production degree decreases, and the injection-production profile is unbalanced. In this paper, through the study of reservoir physical properties, water flooding and control and flooding mechanism and the implementation of fine profile control and flooding on a large scale, the well selection conditions of different reservoirs are obtained, and differentiated countermeasures are formulated. Four optimizations of injection mode to ensure continuous improvement of injection effect and economic benefits.*

Keywords: *Ultra-low permeability reservoir, Dominant seepage channel, Profile control and flooding, Dual-control technology system*

1. Introduction

The main development target of JY oilfield is ultra-low permeability reservoirs with low reservoir permeability. As the permeability decreases, the starting pressure gradient rises sharply, and the establishment of an effective displacement pressure system is slow. The main oil reservoir has entered the development stage of medium water cut, and water flooding intrudes along the dominant channels such as fractures and high-permeability strips on the plane (835 wells seen in total), resulting in plane contradictions; the production degree on the section decreases (the proportion of wells with uneven water absorption is 48.8%), the injection-production profile is unbalanced. Therefore, it is of great significance to study a mature profile control and flooding system for stable production of old oilfields , as shown in Figure 1.

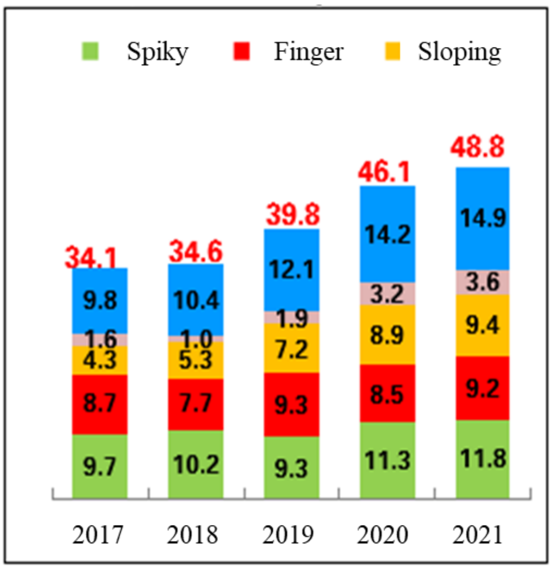

Figure 1: Proportion of wells with uneven water absorption over the years

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2. Formulate differentiated driving strategies

2.1. Research on physical properties of reservoir

2.1.1. Pore characteristics

The Jurassic and Triassic reservoirs in the JY area are dominated by intergranular pores and feldspar dissolved pores, with a small amount of detrital dissolved pores, intercrystalline pores and micro-fissures, with an average surface porosity of 3.7-9.44%[1-2].

2.1.2. Pore throat features

The Jurassic is a mesoporous fine-throat pore structure, the Chang 2 layer is a small-pore fine-throat pore structure, and the Chang 4+5~Chang 8 layer is a small-pore fine-throat pore structure.

According to conventional physical property analysis, it can be known that:

Yan 9 is a low permeability reservoir: the average porosity is 13.88%, and the average permeability is 22.88mD;

Chang 2 is an ultra-low permeability reservoir: the average porosity is 14.75%, and the average permeability is 3.74mD;

Chang 4+5 is an ultra-low permeability reservoir: the average porosity is 11.89%, and the average permeability is 0.92mD;

Chang 6 is an ultra-low permeability reservoir: the average porosity is 11.24%, and the average permeability is 0.39mD;

Chang 8 is an ultra-low permeability reservoir with an average porosity of 10.87% and an average permeability of 0.55mD.

2.2. Characteristics of water flooding

Researches on dominant seepage channels, seepage laws and water breakthrough characteristics of different reservoirs have been carried out:

Low-permeability reservoirs: mainly pore-type water breakthrough, the mainstream throat radius is 2.47 μm, and the water breakthrough period is more than 6 years;

Special-super-I reservoir: mainly pore-fracture type water breakthrough, the mainstream throat radius is 1.53 μm, and the water breakthrough period is 2-6 years;

Super II-III reservoirs: Fracture-type water breakthrough is dominant, the mainstream throat radius is 0.11 μm, and the water breakthrough period is less than 2 years.

2.3. Control and drive mechanism

2.3.1. Identification of the dominant channel

The dominant channel between oil and water wells is mainly composed of three types of fractures:

The dynamic fractures are distributed within 50 meters around the water injection well, and the opening fractures are 100μm-2mm wide;

The micro-fractures are distributed 50 meters away from the well, and the fracture width is 5-8 μm, which reduces the specific surface area of the reservoir and greatly increases the reservoir permeability.

2.3.2. Profile Modulation of PEG Single-Phase Gel

It has the advantages of stable gel formation, single component, controllable particle size (hundred microns), good dispersibility, and strong ability of deep regulation and displacement.

Blocking mechanism: single particle directly blocks (pores), multiple particles bridge and block (micro-fractures, large pores); selectively enter and block high-permeability sections, occupy dominant water flow channels, and expand swept volume. The particle size is 20-300μm, and the radius of action is 20-50m , as shown in Figure 2 and Figure 3.

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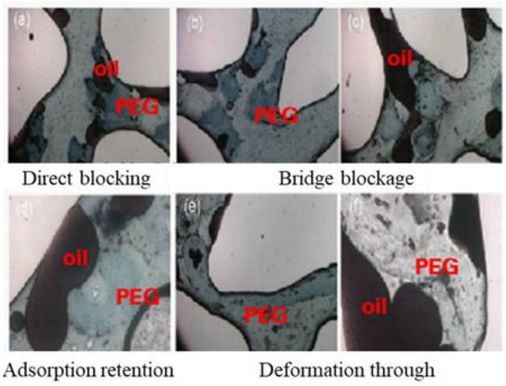

Figure 2: Physical model test (glass etching model)

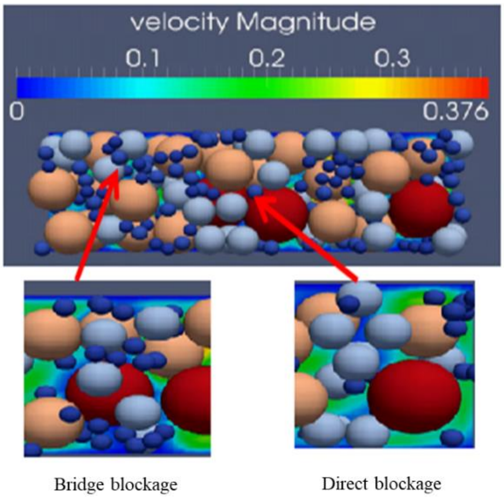

Figure 3: Numerical simulation experiment (three-dimensional fluid-structure interaction/unequal-diameter stacking)

2.3.3. Deep control and flooding of polymer microspheres

The nano-sized polymer microspheres stay in the pores, increase the internal specific surface area, reduce the permeability of the high-permeability layer, and expand the swept volume of water flooding[3-4]. Theoretically, the kozeny equation is as follows:

$$K=\frac{c\phi^3}{\tau\cdot S^2} \longleftarrow \text{specific surface area}$$

Plugging performance: The polymer microspheres have better plugging performance in the deep reservoir, and the sealing performance is stronger in the zone where the seepage velocity between oil and water wells is slower (1m/d or 0.1mL/min). The particle size is 50-300nm, and the radius of action is 50-200m , as shown in Figure 4.

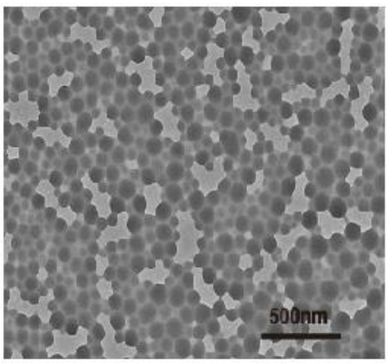

Figure 4: TEM image of polymer microspheres

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2.3.4. Pore-throat matching relationship

The characteristics of roars are mainly pore shrinkage type, sheet type and capillary type, and the ultra-low permeability reservoir is mainly capillary type , as shown in Figure 5.

Pore shrinkage type: obvious pore space and narrow pore throat space; (0.5<K<1.0mD, ultra-low permeability type I);

Flake type: Compared with the pore shrinkage type, the seepage property is better, and the pores are relatively small; (K>1.0mD, extra low permeability);

Capillary type: the pore and throat are integrated, the seepage is poor, and the roar is small and complex. (K<0.5mD, ultra-low osmolarity II+III class).

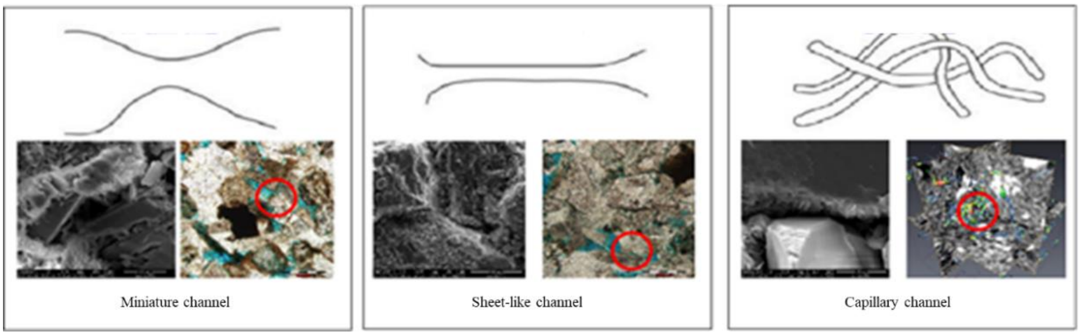
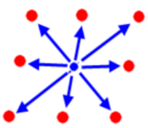
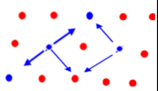
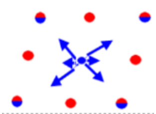


Figure 5: Pore throat types

2.4. Well selection criteria

The micro-scale PEG regulator has a good initial effect, directly blocking the high-permeability channels near the wellbore, and cannot reach the deep; standard , as shown in Table 1.

Table 1: Standard for Well Selection for Water Plugging and Displacement in H Oilfield

Way	Constituency Principle					Schematic	Njected Particle Size (um)	Constituency Result
	Reservoir Type	Displacement Type	Preferred Block	Pore Throat Diameter (um)	Development Features			
Polymer microsphere flooding	Ultra-hypotonic and ultra-hypotonic	Uniform	G60	0.43	In the early and middle stages of development, the water cut is less than 50%, and pressure flooding is basically established		0.1	The injected particle size is 1/3 of the pore throat diameter to form bridging and plugging
			G155	0.72			0.1	
			L1 Southeast	0.43			0.1	
			H3 Long 8 Southeast	0.41			0.05	
PEG water plugging profile control	Ultra-hypotonic	Cracked	H3 long 6	0.29	In the middle of the development, the water seeping time is within 2 years, and the water seeping in multiple directions		300	Direct blocking
			H57 long 8	0.39			300	
PEG water plugging and profile control + polymer microsphere flooding	Ultra-hypotonic	Pore-fracture type	G43 long 4+5	0.24	Development of local micro-fractures in the early and middle stages of development		300	
			G116	0.37			300	

2.5. Develop differentiated countermeasures

According to different development stages and different production characteristics, through mine practice and plate identification, differentiated control and flooding policies and water injection policies for different reservoirs are formulated, and reasonable injection parameters and water injection intensity suitable for development stages are formed, as shown in Figure 6 and Figure 7.

Governance Type:

Area A: Single-point treatment of plane cracks mainly sees water

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Area B: uneven water absorption of multi-system governance profiles, combined with the effect of regulating and flooding

Area C: Water channeling is controlled at a single point, and control and flooding are the main aspects on the surface.

Area D: Mainly focus on the expansion and spread of deep regulation and flooding

The effect of profile control and flood control + injection and production adjustment:

Zone Ⅰ: Controlled water injection to maintain reasonable pressure

Zone II: maintain energy, optimize water injection locally

Zone III: Moderately strengthen water injection to supplement energy

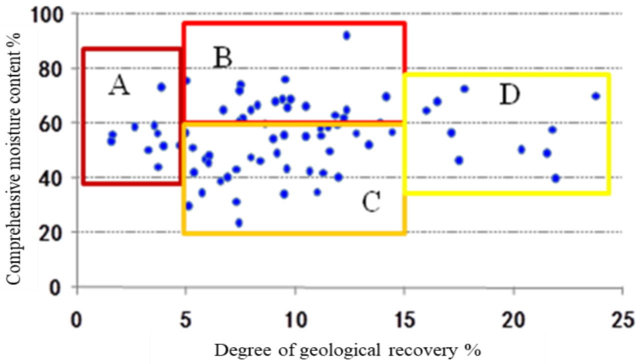

Figure 6: Chart of recovery degree and water cut in control flooding area

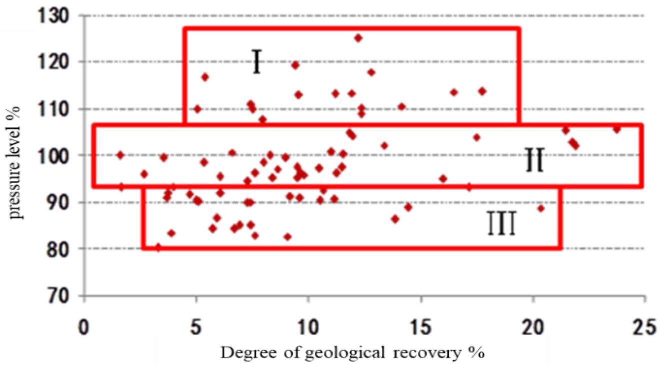

Figure 7: The level of recovery and pressure maintenance in the control and flooding area

3. Based on the study of seepage characteristics and flooding experiments, four optimizations were carried out to achieve precise control and flooding

By carrying out four optimizations of injection parameters, water injection policy, plane liquid production, and injection method, the injection effect and economic benefits are continuously improved.

3.1. Optimization of injection and production policies

3.1.1. Optimization ideas:

①With the expansion of the swept volume, the imbalance of injection and production leads to insufficient local energy, and the supporting water injection is strengthened;

②The waterline of some units is fast advancing, and cannot form an effective bridging and blocking, and it is matched with mild water injection;

③ Some units have a short period of validity for profile control and flooding, and the supporting periodic water injection.

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3.1.2. Workload and effect

An average of 350 to 400 well-times of supporting water injection adjustment per year, and about 80 wells were optimized for liquid production intensity, which achieved continuous improvement of injection effect, and formed three aspects related to profile control and flood control and optimization of injection and production policies. Combined supporting technologies.

3.2. Injection parameter optimization

According to the mainstream dominant seepage channels and the distribution of dominant seepage pores in the reservoir, the particle size and concentration are continuously optimized and the effect of profile control and flooding is improved through particle size selection plate selection, plugging efficiency comparison and plane sand filling model experiments.

3.2.1. Particle size optimization

The mainstream dominant seepage pore, the dominant seepage pore permeability is less than 500mD. According to the chart, 100nm and 50nm particle size microspheres are preferred , as shown in Table 2 and Figure 8.

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

Particle size	Concentration/ %	Injection volume/ PV	Water flooding permeability before plugging /mD	Water flooding permeability after plugging /mD	Blocking rate /%
100nm	0.2	0.3	186	13	928
300nm	0.2	0.3	1512	131	91.3
5um	0.2	0.3	359	133	62.9

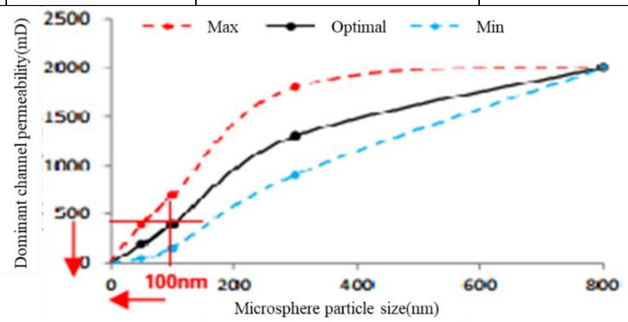

Figure 8: Particle size injection selection diagram of polymer microspheres

3.2.2. Concentration optimization

Comparative analysis of plane sand filling model experiment: low concentration (0.2%), long slug (0.3PV) injection process improves the water flooding sweep volume, and the polymer microspheres use less material and are more economical , as shown in Figure 9.

Three kinds of profile control and flooding technical parameters are formed: polymer microsphere flooding: 50-100nm, 0.2%, 8t; large-dose deep control flooding: 50-100nm, 0.1%, 20t; PEG single-phase gel: 100-300μm, 0.2-0.4%.

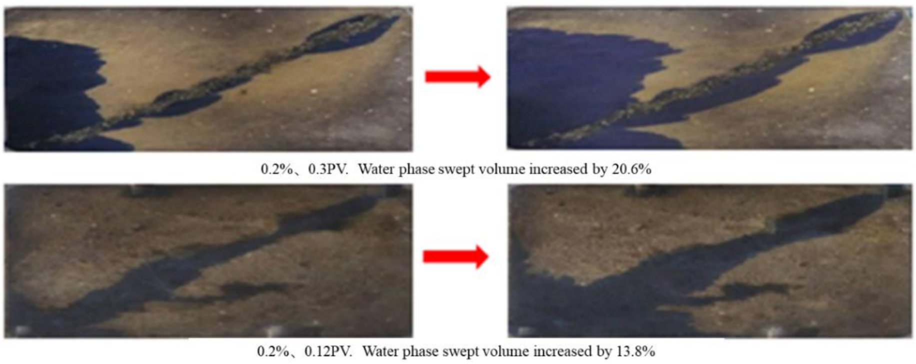

Figure 9: Comparison of water flooding swept volume between two injection processes in the plane sand filling model experiment

In view of the good early effect of some oil reservoirs and the deterioration of the effect of multiple rounds, the optimization of parameters such as particle size and concentration is carried out on an average of more than 160 wells per year. After optimization, the main evaluation indicators such as efficiency and daily oil increase have improved significantly , as shown in Table 3.

Table 3: Comparison of optimization parameters for profile control and flooding in 2020-2021

block	Optimization basis	Adjust the date	Optimize the number of wells	Optimize content		Before optimization		Optimized	
				Implanted particle size (nm)	Concentration (%)	Efficiency (%)	Daily increase(t)	Efficiency (%)	Daily increase (t)
G155	Small particle size, low concentration, improve sealing efficiency	2020.5	38	100↓50	0.1	124	4.8	27.6	9.8
G43 long 4+5		2020.5	40	50	02↓0.1	8.3	1.9	36.1	72
L1 Southeast		2020.4	41	100↓50	02↓0.1	18.3	7	42.6	15
L1 South		2020.7	43	100	02↓0.1	29.2	6.5	33.3	11.3
L1 Southwest, Central		2021.1	72	100↓50	02↓0.1	47.4	124	52.6	16.5
H3 long 8		2021.1	30	50	02↓0.1	252	10.2	30.6	13.7
G63		2021.4	26	100↓50	0.1	19.3	6.3	26.1	9
H57 long 8		2021.7	10	100	0.2↓0.1	Not effective	/	31.6	4.7
L1		2021.7	37	50	0.1↓0.05	34.6	2.4	34.6	3.6

3.3. Optimization of injection method

Adhere to the centralized and contiguous implementation of oil reservoirs, and the fine plan design of each unit, forming a low-cost, easy-to-manage, safe and environmentally friendly process injection mode, and the cost of single-well implementation of microspheres has been reduced by 55,000 yuan in the past three years[5].

Mainline injection: Compared with 2019, in 2021, when 389 more wells are implemented, 69 sets of injection equipment will be reduced, and the annual equipment rental cost will be saved by 3.86 million yuan.

Self-implementation: canceling technical services, self-dosing of microspheres, self-profile adjustment of PEG, and annual cost savings of 4.18 million yuan , as shown in Figure 10 and Figure 11.

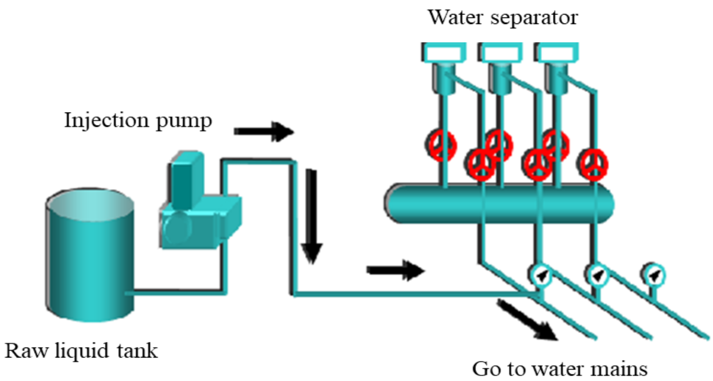

Figure 10: Schematic diagram of the centralized online injection of polymer microspheres

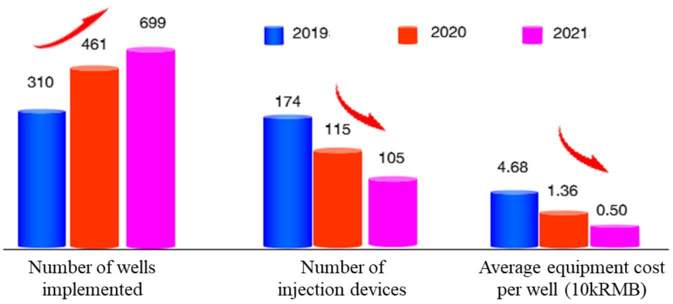

Figure 11: Changes in the injection equipment for polymer microsphere control and flooding in the past three years

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4. Application of results

4.1. Overall effect

Aiming at the problem that the contradiction between the plane and profile of the main oil reservoir has intensified, and the water flooding efficiency has deteriorated, the promotion of profile control and flooding has been continuously increased, covering an output of 1 million tons, accumulative oil increase of 390,000 tons and precipitation of 342,000 cubic meters in the past four years., driving the region's annual natural decline to decrease by 3.4% , as shown in Figure 12 and Figure 13.

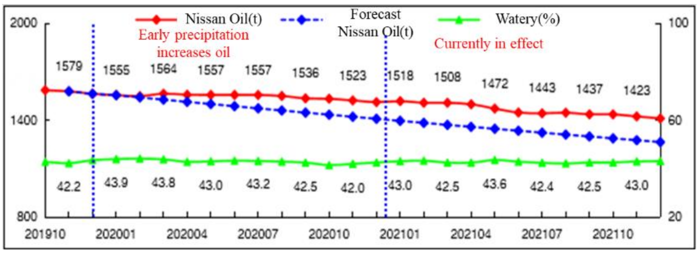

Figure 12: Hyperbolic decrement curve of continuous injection zone in 2020

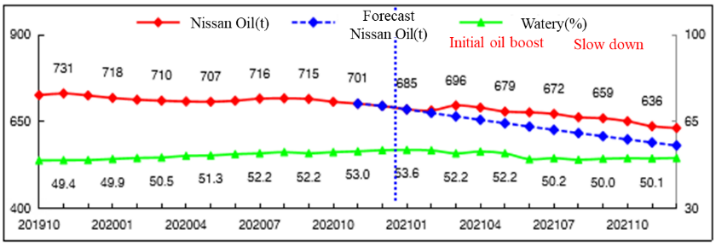

Figure 13: Hyperbolic descending curve of newly added injection areas in 2021

4.2. Adaptive Analysis

(1) When the recovery degree of recoverable reserves of different types of reservoirs is less than 60%, the efficiency of profile control and flooding is relatively high;

(2) When the water content of ultra-low permeability to ultra-low permeability type I reservoirs is less than 60%, it is the best time for large-scale adjustment and flooding;

(3) When the water cut of the ultra-low permeability II reservoir is less than 70%, it is the best time for large-scale adjustment and flooding;

(4) When the water cut of the ultra-low permeability III reservoir is less than 65%, it is the best time for large-scale adjustment and flooding , as shown in Figure 14 and Figure 15.

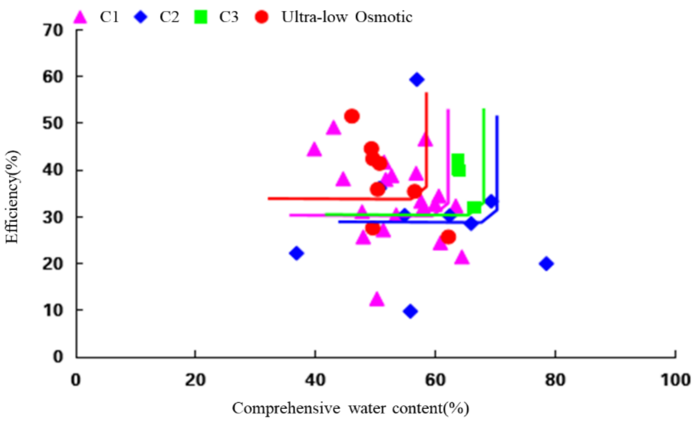

Figure 14: Comprehensive water-cut-adjustment-flooding efficiency diagram by reservoir

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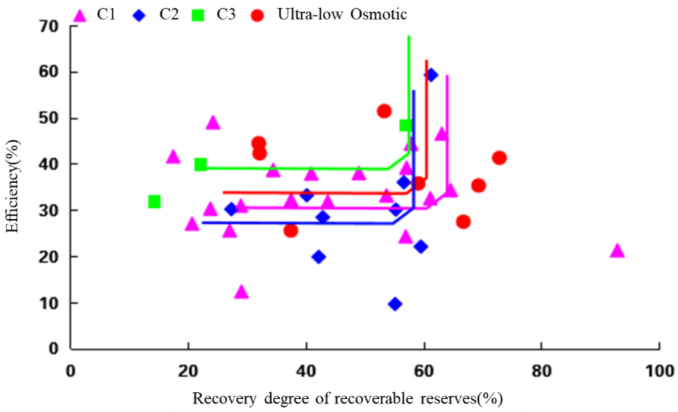

Figure 15: The recovery degree of recoverable reserves in different reservoirs - the efficiency of control and flooding

4.3. Application of results

A technical model of "microsphere+" synergistically improving the water flooding effect of the reservoir has been initially established.

At present, microspheres have become the core technology for adjusting reservoir heterogeneity and improving water flooding in Jiyuan Oilfield, and a series of "microsphere +" collaborative technology models have been initially established.

Microsphere + injection-production adjustment: combination of regulation and flooding with balanced water injection, controlled water injection, periodic water injection, and rational liquid extraction policies;

Microsphere + water plugging and profile control: combined control and flooding with PEG-1, PEG-2A, online microgel profile control and other multi-system processes to improve oil recovery;

Microsphere + infill adjustment: combination of drive adjustment and development well pattern adjustment;

Microsphere combination particle size control: 100nm+50nm combined particle size, synergistically improve the water flooding effect.

(1) Ultra-low permeability reservoir - multi-system governance model of plugging, regulating and flooding

PEG-1 gel occupies the dominant channel of water flow, blocks large pores, and promotes the diversion of liquid flow in asymmetric and mainstream linear well groups;

PEG-2A profile control improves water absorption form and profile water flooding, and increases the degree of water driving; long-period microsphere flooding is matched with a balanced water injection policy, which effectively expands the swept volume of water flooding.

Such as: G155 Chang 1 reservoir implementation effect: porosity 14.7%, permeability 6.5md, water cut 46.6%, pressure level 102.1%, 45 wells, injection particle size 50nm, injection concentration 0.1%, injection volume per well 20t. The efficiency is 41.4%, the single well group increases oil by 213t, the natural decline is 10.8↘7.1%, and the water cut rise rate is 2.4↘0.9%.

(2) Ultra-low permeability type I reservoirs: - Forming a small particle size, low concentration, equal injection, long-period control and flooding mode.

G60 Reservoir: Comprehensive water cut is less than 60%, in the middle stage of development, and microspheres + injection-production adjustment synergistically improve the development effect.

The combination of regulation and flooding with development technology policies forms the overall long-term injection + injection-production adjustment model of the reservoir. In the process of deep regulation and flooding, guided by pressure and water cut changes, the water injection policy of “strengthening first and then balancing” was adopted, and the water injection intensity was optimized from 2.1↑2.5↓2.3m3/d. Port, the wave code was divided into 9 ports, the water flooding was expanded, and the pressure was maintained at a further reasonable level (102.5%).

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Implementation effect: porosity 11.2%, permeability 0.66md, water cut 39.3%, recovery degree 12.0%, 103 wells were implemented, injection particle size was 100nm, injection concentration was 0.1%, and injection volume per well was 20t. The efficiency is 49.2%, the oil increase of single well group is 290t, the natural decline is 12.5↘4.3%, and the water cut increase rate is 0.7↘-0.7%.

H3 Reservoir: The comprehensive water cut is >60%, and the decreasing and decreasing effect can be achieved under the control of fine injection and production.

Implementation effect: porosity 12.5%, permeability 0.60md, water cut 73.9%, pressure maintenance level 80.4%, 12 wells were implemented, the injection particle size was 50nm, the injection concentration was 0.2%, and the injection volume per well was 8t. The efficiency is 32.4%, the single well group has increased oil by 53t, the monthly decrease is 2.6↘0.3%, and the water cut increase rate is 3.5↘3.3%.

5. Understanding and conclusion

1) The dominant channel between the Triassic oil and water wells is mainly composed of three types of fractures. The dynamic fractures are distributed within 50 meters around the water injection well, and the opening width is 100 μm-2 mm; the micro-fractures are distributed 50 meters away from the water well, and the fracture width is 5 -8μm, the specific surface area in the reservoir is reduced, and the reservoir permeability is greatly increased.

2) The micro-scale PEG regulator has a good initial effect, directly blocking the high-permeability channels near the wellbore, and cannot reach the deep;

3) Through continuous exploration and practice, three different technical parameters of water plugging and flood control have been formed.

4) The higher the effect is, the better the pressure maintenance level is between 90-105%, and the pressure maintenance level is too high or too low, which will affect the injection effect.

5) The profile of the fractured water-incoming zone is adjusted upward, the dominant channel is blocked, and the flooding is adjusted on the surface, so as to realize the first plugging and then the flooding, and balance the plane liquid production, and the water flooding efficiency is significantly improved.

6) Ultra-low permeability and ultra-low permeability Class I/II reservoirs: plugging is the main method in the initial stage of development, and dynamic fractures are plugged to expand macroscopic plane sweep; Spread; deep regulation and flooding in the late development stage to expand the deep spread of the reservoir.

7) Reasonable injection-production technical policies (pressure maintenance level, injection-production ratio) play a key role in improving the effect of profile control and flooding. After the polymer microsphere control flooding, with the continuous expansion of the swept volume of water injection, the water injection policy should be optimized in time, and policies such as balanced water injection and periodic water injection can prolong the control and flooding effect.

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