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Research and Application of Profile Control System for Buried Hill Fractured Reservoirs in Bohai Oilfield

Changting Pang, Yanyue Li, Wenbo Bao, Jinlong Lv, Hui Li

CNOOC China Limited, Tianjin Branch, Tianjin 300459, China

Abstract: In order to solve the problem of continuous deterioration of water injection effect in Bohai buried-hill fractured reservoirs, a temperature-resistant profile control system for controlling fractures was developed. Through the selection of polymer, crosslinking agent and crosslinking agent, the profile control system with the formula of 3000-4000mg/L polymer+ 3000mg/L crosslinking agent+2500mg/L crosslinking agent is optimized. Indoor evaluation experiments show that the gelling time of the profile control system is more than 65 hours, the strength is more than F level, no obvious dehydration occurs after aging for 60 days at high temperature, the plugging rate of the fractured core reaches more than 99%, the matrix remaining oil can be started, and the recovery factor is increased by 27.20%. Field application shows that the profile control system has successfully blocked the water channeling fractures between oil and water wells, the maximum water cut reduction is 45%, and the oil increase effect is remarkable.

Keywords: Bohai oilfield; fracture; buried hill reservoir; profile control.

1. Foreword

Fractured buried hill reservoir refers to the reservoir formed by the accumulation of oil and gas in the fractured buried hill trap. The main difference between it and conventional fractured reservoirs is that the former oil and gas accumulate in buried hill traps, while the latter oil and gas accumulate in conventional traps. Buried hill traps and fracture systems are the main geological characteristics of fractured buried hill reservoirs[1-3]. Buried hill trap is the main place for oil and gas to accumulate, and fractures are the main seepage channels for oil and gas to flow in the reservoir. "Buried hill" reflects the type of reservoir trap and is the macroscopic description of reservoir body. The "fracture" is one of the key factors affecting the reservoir space type, physical characteristics, seepage characteristics and development characteristics.

Fractured buried hill reservoirs are often developed by water injection in the middle and late stages of production to maintain formation pressure, and the injected water flows along the fractures, so that the production wells along the direction of the fractures are flooded, the water cut of the reservoir rises rapidly, and the reservoir enters the high water cut stage in a very short time. The characteristics of water injection development in fractured reservoirs are mainly as follows: obvious direction of water injection effect, strong water absorption capacity, low injection pressure, rapid increase of water cut, and large remaining reserves after water flooding [4-6].

X Oilfield in Bohai Sea is a typical buried hill reservoir with a burial depth of 1600~1880m. The reservoir is mainly composed of metamorphic rock and gneiss granite, belonging to fractured reservoir of metamorphic rock buried hill. Only semi-weathered crust is formed by long-term weathering and denudation, and the cracks are very developed. The upper part of the semi-weathered crust is full of weathering products and has strong heterogeneity; the bottom cracks of the semi-weathered crust are relatively open and have good connectivity, but the density is significantly lower than that of the upper part [7-9]. The fractures are mainly high dip angle inclined fractures (20°~60°), the main strike direction is NE-S-W direction, the secondary direction is NW-SE direction, and the fracture density is 0.5~3.5/m. Logging interpretation shows that the total porosity is 6.8%, the average porosity of the fracture system is 1.08%, and the average permeability is (97~927) $\times 10^{-3} \mu m^2$; the average porosity of the matrix system is 5.69%, and the average permeability is less than $1 \times 10^{-3} \mu m^2$. The original formation pressure of the reservoir is 17.50 MPa, the saturation pressure is 10.25MPa, and the crude oil density is 0.80 g/cm^3 [10].

During the development process, three development strategies have been adopted, namely, depressurization development, stable water injection and unstable water injection. At present, the current pressure coefficient (0.6) of the buried hill reservoir is lower than the reasonable formation pressure maintenance level, and problems such as formation degassing and liquid production decline have occurred in the oilfield, so normal water injection is urgently needed to alleviate the formation pressure decline and even gradually restore the formation pressure. Because of the special geological conditions, the fractures between the downflow well and the displaced well are very rich, and the permeability of the fractures is very high, and the seepage speed is fast, so the injected water is very easy to flow along the fractures, eventually causing the production well water flooding and channeling, resulting in the gradual deterioration of water flooding effect in the oilfield. In order to solve the problem of poor waterflooding effect in Bohai fractured buried hill reservoirs, it is necessary to develop a temperature-resistant profile control system suitable for fracture control.

2. Experimental Part

2.1. Experimental instruments and materials

Electronic balance, electric stirrer, wire bottle, beaker, constant temperature oven, Brookfield viscometer, core displacement device, etc.

Temperature-resistant polymer (molecular weight 9-20 million), crosslinking agent, crosslinking agent, field injection water of X oilfield, simulated crude oil (2.55 mPa·s at 90℃), artificial core.

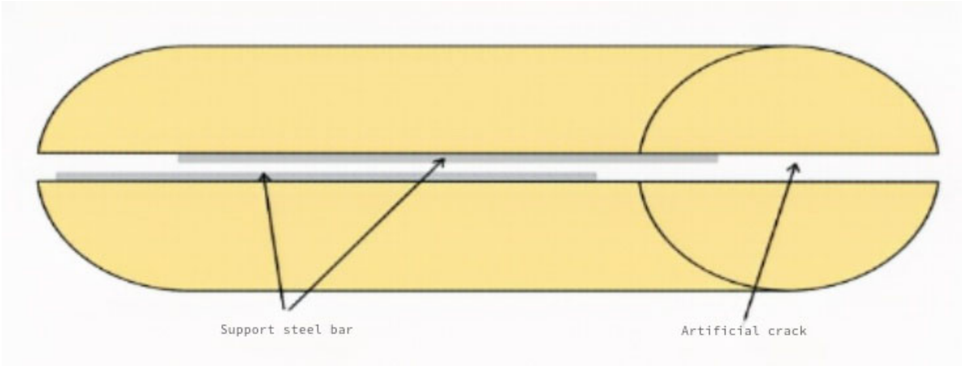

Figure 1. Schematic Diagram of Core Fracture

2.2. Experimental procedures

2.2.1. System formulation optimization

(1) Prepare a certain concentration of polymer mother solution with field injection water, and test the time and viscosity required for complete dissolution; test the viscosity again after shearing the polymer solution at a high speed of 1000 RPM for 1 min, and calculate the viscosity retention rate.

(2) adding the crosslinking agent and the crosslinking auxiliary agent into the preferred polymer solution with certain concentration according to a certain proportion, bottling and sealing the mixture after stirring and mixing the mixture uniformly, and aging the mixture in a constant temperature oven at 90℃ to preferably obtain a system formula with better gelling effect.

2.2.2. Experimental evaluation of system displacement

(1) washing and drying a cemented core, weighing the dry weight, injecting water into a saturated field, weighing the wet weight, and calculating the porosity;

(2) testing the matrix permeability of the core by water flooding, filling a steel sheet with the thickness of 0.5cm after the core is cut, calculating the fracture volume FV, and testing the fracture permeability again;

(3) Inject a 5PV profile control system into the core with fractures to test the injectivity, and carry out subsequent water flooding after aging for 3 days at 90℃ to test the plugging property.

(4) The core matrix and fractures were saturated with simulated oil respectively, and the profile control performance was tested by water flooding to 98% water cut, injecting 1FV profile control system (containing 0. 1FV polymer displacement fluid), aging at 90℃ for 3 days, and then subsequent water flooding.

3. Results and Analysis

3.1. System optimization

3.1.1. Polymer preference

(1) Type of polymer

The solubility and apparent viscosity of the four temperature-resistant polymers were evaluated, and the experimental results are shown in the following table. By comparing the experimental data, it is found that the dissolution time of KW-1 and KW-3 polymers is less than 60 minutes, which meets the requirements of field liquid preparation. Considering the viscosity loss of the system caused by the mechanical shear effect of pipeline valves and other places in the field injection process, KW-3 polymer with higher viscosity retention rate was selected.

Table 1. Evaluation of basic properties of polymers

Type of polymer	Molecular weight	Mother liquor concentration	Dissolution time	Viscosity	Viscosity retention after shearing
KW-1	9 million	5000mg/L	20min	138mPa·s	50%
KW-2	10 million		70min	172mPa·s	75%
KW-3	15 million		45min	246mPa·s	85%
KW-5	20 million		85min	332mPa·s	87%

(2) Polymer concentration

Dilute the preferred KW-3 polymer mother liquor into 4 parts with a concentration of 1000-4000 mg/L, and add 2500 mg/L crosslinking agent and 2500 mg/L crosslinking assistant respectively. The gelling test results are shown in the following table. When the polymer concentration is low, the system does not gel or the gel strength is low, which can not meet the plugging requirements; when the polymer concentration is high, the system stability is poor, so the preferred polymer concentration of KW-3 is not less than 3000 mg/L.

Table 2. Effect of polymer concentration on gelling effect

Polymer KW-3 concentration	Initial viscosity	Gelling time	Gelling strength	Dehydration rate after 60 days
1000mg/L	43mPa·s	Not gelled	A	/
2000mg/L	66mPa·s	75h	D	<10%
3000mg/L	96mPa·s	65h	F	<10%
4000mg/L	152mPa·s	32h	F	<10%

3.1.2. Prefer crosslinking agent

Fix the concentration of KW-3 polymer at 3000 mg/L and the concentration of crosslinking agent at 2500mg/L, and add 1500-4000mg/L crosslinking agent FQ respectively. The experimental results are shown in the following table. With the increase of crosslinker concentration, the gelation time decreases and the strength increases. Considering the gelation effect and stability, the optimal crosslinker concentration is 3000 mg/L.

Table 3. Effect of crosslinker concentration on gelling effect

Crosslinker FQ concentration	Initial viscosity	Gelling time	Gelling strength	Dehydration rate after 60 days
1500mg/L	90mPa·s	100h	C	<10%
2000mg/L	93mPa·s	80h	D	<10%
3000mg/L	96mPa·s	65h	F	<10%
4000mg/L	97mPa·s	12h	F	>10%

3.1.3. Optimization of crosslinking agent

Fix the concentration of KW-3 polymer at 3000 mg/L and the concentration of cross-linking agent FQ at 3000 mg/L, and add 1000-3000 mg/I cross-linking agent respectively. The experimental results are shown in the following table. The addition of crosslinking agent could effectively delay the gelling time of the system, but when the concentration was too high, the gelling strength of the system was reduced, so the optimal concentration of crosslinking agent was 2 500 mg/L.

Table 4. Effect of concentration of crosslinking agent on gelling effect

Crosslinking aid concentration	Initial viscosity	Gelling time	Gelling strength	Dehydration rate after 60 days
1000mg/L	94mPa·s	10h	D	<10%
2000mg/L	96mPa·s	24h	D	<10%
2500mg/L	96mPa·s	65h	F	<10%
3000mg/L	97mPa·s	120h	C	<10%

Based on the above static gelling experiments, the optimal formulation of the temperature-resistant profile control system is 3000-4000 mg/L polymer KW-3 + 3000 mg/L crosslinking agent FQ+2500 mg/L crosslinking coagent.

3.2. System injectivity and plugging

It can be seen from the data in the figure below that the initial viscosity of the system is low and the fracture permeability is high, so the injection pressure of the system is low and rises slowly, and the injectivity is good. The system can effectively seal the cracks after being filled in the core cracks and aged into gel, the breakthrough pressure reaches 2.3MPa, the plugging rate of continuous subsequent water flooding is still as high as more than 90%, and the system has strong erosion resistance.

Table 5. Experimental parameters of fracture core injection and plugging

Core number	Pore volume	Crack Volume	Substrate Permeability	Crack Permeability	Break through the pressure	Blocking rate
L-1	12mL	8mL	46mD	1836mD	2.30MPa	99.96%

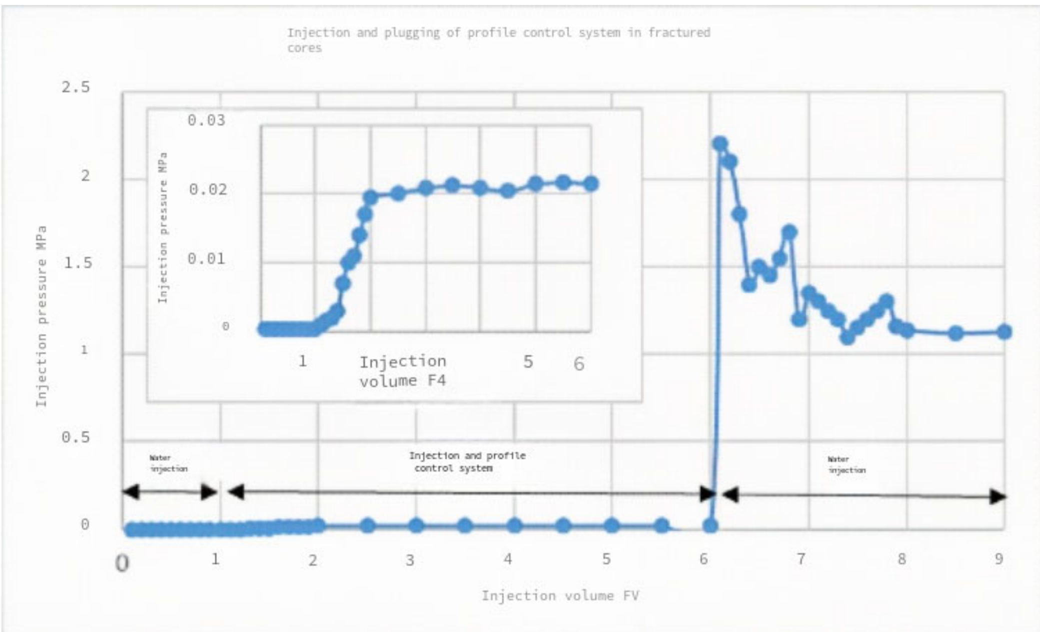

Figure 2. Injection pressure variation curve of profile control system in fractured core

3.3. Profile control performance

It can be seen from the data in the figure below that oil production can be divided into three stages, namely, water-free oil production stage, rapid increase stage of water production and stable increase stage of water production. Due to the existence of fractures, the water flooding front breaks through rapidly in the process of water flooding, resulting in the water cut reaching 100% rapidly, which is a typical feature of fractured reservoirs. The temperature resistant profile control system is injected to block the fracture space, so that the subsequent water flooding seepage channel is changed, the crude oil in the matrix part is diverted, and the recovery rate is improved to 27.20%.

Table 6. Experimental parameters of fracture core profile control

Core Number	Porosity Volume	Crack Volume	Substrate Permeability	Crack Permeability	Water drive Recovery factor	Profile control Recovery factor	Enhanced oil recovery by subsequent water flooding
L-2	13mL	7mL	58mD	1720mD	28.55%	4.80%	22.40%

Figure 3. Profile control system to fracture control ability curve

4. Field Application

The typical downflow well Well1 and the adjacent production well B are both horizontal wells, and fractures are developed between the formations. The injection-production reaction between Well Well1 and Well B is obvious, and there is a large channel between the dynamic reaction wells. It is analyzed that the water injection of Well Well1 has burst into Well B along the fracture, and a water channeling channel has been formed. The water absorption profile of Well 1 layer shows that there is a high water absorption interval, and there is uneven water absorption at the heel and toe. Therefore, it is decided to implement profile control in Well Well 1, plug the high water absorption layer, inhibit the fracture channel along the direction of Well B, adjust the flow direction of injected water, and achieve the purpose of well group water reduction and oil increase.

Based on the recent data of water injection rate and water cut increase of the well group, combined with the volumetric calculation formula, the volume of the temperature-resistant profile control system is designed to be 9200 cubic meters, including 400 cubic meters of trial injection and displacement. The on-site construction process was smooth, the injection pressure did not increase significantly, the construction lasted 41 days, and the cumulative consumption of chemicals was 92.5 tons. After the measures, the water injection was resumed, the comprehensive water cut of the well group decreased by 45 percentage points, and the daily net oil increase reached 182 cubic meters. At present, the water cut continued to decline, and the oil increase continued to rise, indicating that the profile control system successfully blocked the fractures, inhibited the channeling, and started the crude oil in the formation matrix.

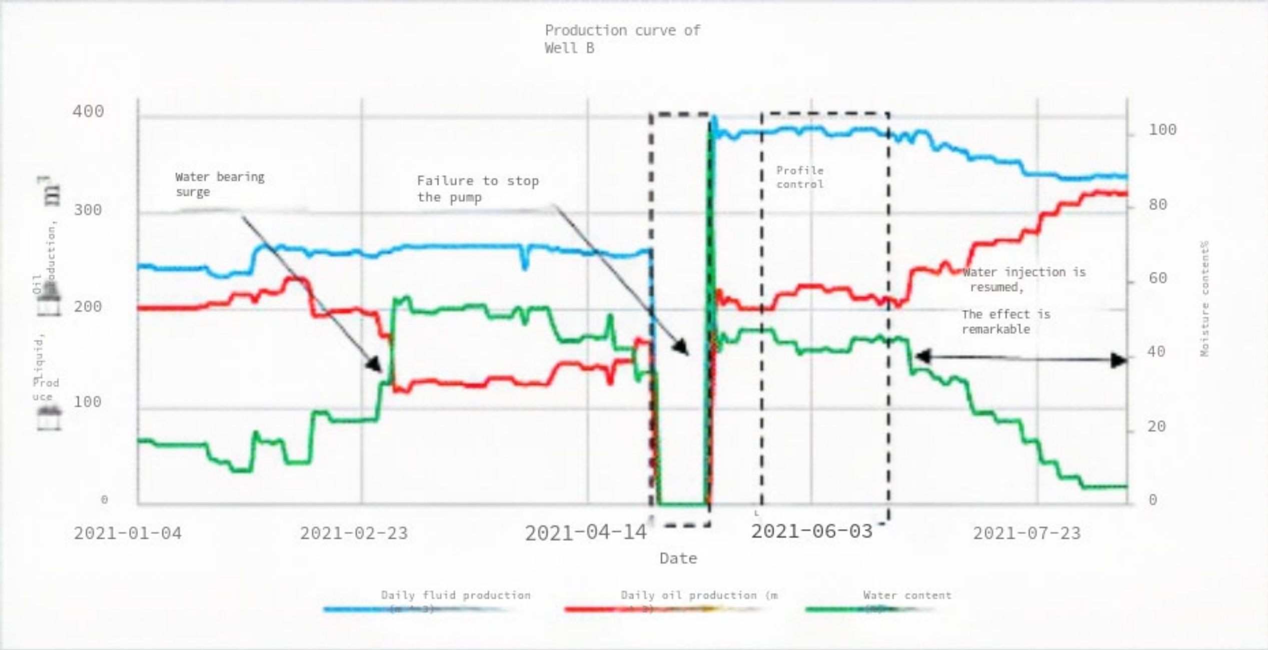

Figure 4. Production curve of profile control system before and after injection

As of October 2022, four well groups of field tests have been carried out in X buried hill fractured oilfield in Bohai Sea, with a cumulative oil increase of 36209 tons, and the oil increase of profile control measures is significant, but the effect of the measures is quite different.

Table 7. Field Application

Construction time	The well number	Profile control fluid volume (m3)	Oil increment (t)
2021.5.19-6.28	Well 1 (Round 1)	9400	17100
2022.3.10-4.16	Well2	8200	16843
2022.4.2-5.6	Well3	7600	1882
2022.4.24-6.20	Well 1 (Round 2)	12200	384

5. Conclusion

(1) According to the conditions of fractured buried hill reservoirs in Bohai Sea, a temperature-resistant polymer gel profile control system suitable for target reservoirs was developed, and its formula was 3000-4000mg/L polymer + 3000mg/L crosslinking agent + 2500mg/L crosslinking assistant.

(2) that temperature-resistant profile control system has low initial viscosity, the gel time can reach more than 65H, the strength can reach more than F level, and no obvious dehydration phenomenon occurs aft aging for 60 days at high temperature.

(3) The profile control system has good injectivity and plugging property in the fracture core, and can effectively plug the fracture channel, with the plugging rate of more than 99%, and start the remaining oil in the matrix, increasing the oil recovery by 27.20%.

(4) 3 wells (4 well-times) have been tested on site, the maximum decrease of water cut is 45%, and the cumulative incremental oil 36209t. Because of the difference of fracture development degree and fracture size, the profile control effect is quite different.

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