Study on Screening and Applying of Selective Water Shutoff Agent For Horizontal Well

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Abstract—According to the situation of water plugging in horizontal well using screen pipe completion in Liaohe oilfield, emulsion polymer gel, relative permeability correctives and oil soluble resin are studied in the paper. Three systems are evaluated in the lab. The results indicate that emulsion polymer gel is fit for point water exit of horizontal well in heterogeneous reservoir, and relative permerbility correctives are fit for multishot water exit of horizontal well in low permeability reservoir, and oil soluble resin is fit for multishot water exit horizontal well in high permeability reservoir. The effect of increasing oil in the oilfields is remarkable.

Keywords-horizontal well; selective water shutoff agent; emulsion polymer gel; relative permeability correctives; oil soluble resin

I. INTRODUCTION

At present, water plugging technology of the horizontal well faces three contradictions. First, the different completion methods of horizontal well put higher requirements forward for plugging agents [1]. Water plugging of casing perforated horizontal well can take the form of combining the mechanical sealing and plugging agent, which has no special requirements on the plugging agent. Second, the adaptability of plugging agent is restrict in the field. The horizontal well structure is different from the vertical wells, which horizontal section is long, and particle plugging agent in horizontal section used to accumulate. Third, the injection devices used in the field have some limitations [2]. At present, facing the contradiction of water plugging in horizontal wells, the choice of plugging agent must accord with some adverse effects, such as completion methods, self adaptability and injection devices.

Researches show that the application of selective plugging agent used in the oil field horizontal well is less [3]. In the paper, the selective plugging agents are studied. Through the lab combined with field practice, three kinds of selective plugging agent system are selected, which are emulsion polymer gel, relative permeability correctives and oil soluble resin.

II. SCREENING AND APPLICATION OF EMULSION POLYMER GEL SYSTEM

Through screening indoor, emulsion polymer gel has some excellent characteristics which are needed for horizontal well water plugging. Gel system is composed of polymer emulsion and LH-2 organic chromium crosslinking agent. The viscosity of crosslinking system is low before it reacts with polymer, so it is easy to inject. The crosslinked viscosity is greater than 100mPa·s, so it can go into heterogeneous formation with selectivity [4]. Polymer emulsion not only has the performance of temperature resistance, salt tolerance, higher viscosity which general polymer does not have, but also has some advantages such as dissolved quickly (<15min), dissolved completely without "fish eye", and good fluidity [5]. The main performance index of emulsion polymer is shown in TABLE Ⅰ.

TABLE I. MAIN PERFORMANCE INDEX OF EMULSION POLYMER

Items	Index
appearance	white water dispersed evenly liquid
pH value	4~6
density, g/cm^3	1.1
solid content, %	40
degree of hydrolysis , %	20
molecular weight, 10^4	900

A. *Dissolution time of emulsion polymer*

It is common to use conductivity method for measuring emulsion polymer dissolution time, and experimental process is as follows. Prepare 5000 mg/L emulsion polymer solution, and put conductivity meter probe into solution, and record a solution conductivity value every minute until the conductivity values remain unchanged within 5 min.

Emulsion polymer was dissolved in sewage of Liaohe Oilfield. At the beginning, water conductive ability was strong, and conductivity decreased with the continuous dissolution of polymer emulsion, finally conductivity tended to be stable. The inflection point is the dissolution time of the polymer. The results of conductivity are shown in Fig .1.

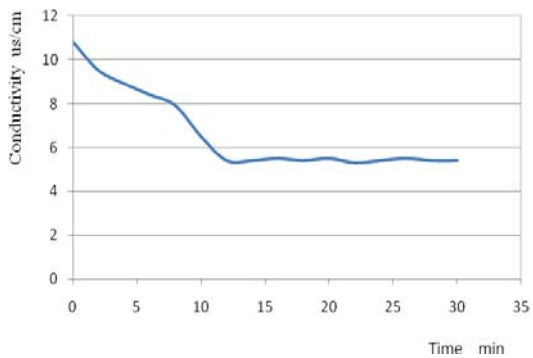

Figure 1. Dissolution time test

From the experimental results we can know that the dissolution time of the emulsion polymer is lower than 15min in the sewage, which is favorable for the rapid preparation in the field.

B. *Shear resistance of emulsion polymer*

Took Gao1 block sewage to prepare the emulsion polymer, and the concentrations were 1500, 2000, 2500 mg/L. The polymer solution went through the anti-sand equipment under 0.5MPa N_2, and measured shear viscosity of the solution. The results are shown in TABLE Ⅱ.

TABLE II. EXPERIMENTAL RESULTS ON THE SHEAR RESISTANCE OF EMULSION POLYMER SOLUTION

Polymer concentration, mg/L	Initial viscosity, mPa·s	Shear viscosity , mPa·s	Viscosity retention rate, %
1500	10.5	8.7	82.9
2000	13.4	10.9	81.3
2500	16.9	13.7	81.1

The results show that the polymer emulsion has stronger shear resistance. With the increasing polymer concentration, viscosity retention rate is on a downward trend. The emulsion polymer shear viscosity retention rate is more than 80%.

C. *Optimization experiment of the emulsion polymer gel formulation*

The experimental method of formulation optimization is as follows. Gao1 block sewage was used to dissolve the emulsion polymer, and the temperature was 70℃. The polymer concentration of emulsions were 1500, 1800, 2000, 2200, 2500, 3000, 4000mg/L. LH-2 organic chromium crosslinking agent concentrations were 800, 1000mg/L. Added LH-2 organic chromium crosslinking agent into the certain concentration of emulsion polymer solution, and shaked the system evenly, then put the system into incubator kept 72h at 70℃. The viscosity of polymer solution was measured by RS150 rheometer model, and the viscosity of crosslinking system was measured by RS150 rheometer at oscillation mode. Experimental results are shown in Fig .2.

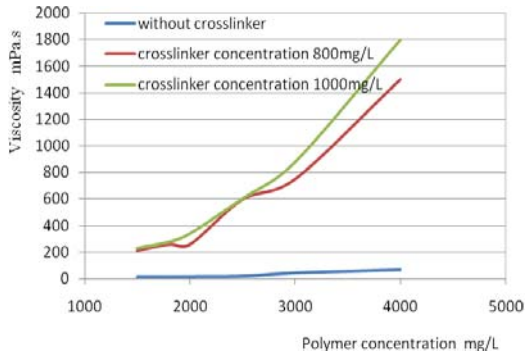

Figure 2. Experimental results of cross linking at different concentration(70℃)

The experimental results show that the emulsion polymer can crosslink effectively with LH-2 organic chromium crosslinking agent in Gao1 block sewage. The viscosity of the system increases obviously. With the concentration of polymer and crosslinking agent increasing, the viscosity of the system increases.

Considering the strength requirements of water shutoff agent used in the horizontal well, combined with the laboratory evaluation results, polymer emulsion frozen gel system formula is determined as follows: emulsion polymer concentration is greater than 4000mg/L, and LH-2 organic chrome crosslinking agent concentration is greater than 1000mg/L.

D. *Thermal stability of emulsion polymer*

Polymer emulsion frozen gel was prepared as follows: took Gao1 block sewage to dissolve polymer emulsion, and polymer concentration was 2000mg/L, and crosslinking agent concentration was 1000mg/L. The temperature was 70℃. After gelled, the system was kept for 90 days at 70℃, and the viscosity retention rate was still larger than 70%. Experimental results are shown in Fig .3.

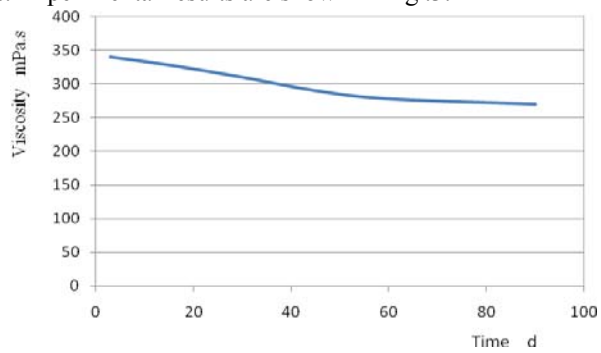

Figure 3. Thermal stability of emulsion polymer gel system

E. *Field application of emulsion polymer gel system*

Take Gao1-P1well for example. According to the analysis of drilling trajectory data, the end of the horizontal section of the vertical depth is too low, and the horizontal section is near the level of oil water interface. There is active water at the edge and bottom. Because of above the bottom water of the reservoirs without tight layer, and reservoir permeability is heterogeneity in vertical, the formation water whose flow resistance is relatively small is more easily to go into the wellbore in the same production pressure. It can be concluded that flow channel has been formed.

In the field, the emulsion polymer gel system was used to implement for horizontal well water shutoff. It was injected by using the light pipeline. The total intake volume was 1550m^3. The injection rate was 5.0m^3/h ~ 8.0m^3/h. The initial pressure was 0, and the maximum pressure was 7.8MPa. After water plugged, daily oil production rose from 2.5t to 27.1t and water cut decreased from 70% to 98.2%. The production oil of the well accumulated 2440t. The effect of increasing oil was remarkable.

III. EVALUATION OF RELATIVE PERMEABILITY CORRECTIVES

The mechanism of relative permeability correctives are changing the wettability of rock surface and increased water flow resistance. Relative permeability correctives have the following properties [6]. First, it can be firmly adsorption in the stratum needed water control. Second, the molecule of relative permeability correctives can stretch when it encounters water, and it can form a stable

network structure, which can increase resistance of water molecules passing through. Third, when it encounters oil molecules, relative permeability correctives molecular system contracts, which can reduce the resistance of crude oil passing by. Fourth, relative permeability correctives molecule on demanding environment can exist stably without decomposition [7]. Fifth, it can reverse the rock surface wettability, which leads the crude oil molecules can not adsorbed on the surface of the rock. These properties can meet the selective plugging water requirements of the low permeability reservoir, multi-point water outlet and pipe completion for horizontal well. Therefore, the evaluation are carried out indoor.

A. *Evaluation method*

1) *Test equipment and materials*

Core flow experimental instrument, pressure sensor and pressure gauge, different permeability artificial core filled with quartz sand, crude oil, kerosene, simulated formation water (salinity is 5727mg/L).

2) *Test procedure*

a) Measure the change rate of water phase permeability

Measure the water phase permeability before injection; inject 1PV 0.5% relative permeability correctives in opposite directions; keep static 24h; inject simulated water; measure the water phase permeability after injection.

b) Measure the change rate of oil phase permeability

Measure the oil phase permeability before injection; inject 1PV 0.5% relative permeability correctives in opposite directions; keep static 24h; inject simulated oil; measure the oil phase permeability after injection.

B. *Determination of water phase permeability, plugging rate, and oil recovery rate*

1) *Change rate of oil phase permeability*

The parameters of artificial core filled with quartz sand are shown in TABLE Ⅲ.

TABLE III. THE PARAMETERS OF ARTIFICIAL CORE FILLED WITH QUARTZ SAND

Parameters	Single tube model 1	Single tube model 2
diameter, cm	2.5	2.5
length, cm	19.0	19.0
permeability, $\times10^{-3}\mu m^2$	516.1	610.2
pore volume, mL	16.0	17.0

The test temperature is 70℃, and the relative permeability correctives injection rate is 2 mL/min. The decline rate of oil phase permeability is 25% (plugging oil rate). The test results are shown in TABLE Ⅳ.

TABLE IV. TEST RUSULTS

No.	Pemeability before plugging K1, $\times10^{-3}\mu m^2$	Pemeability after plugging K2, $\times10^{-3}\mu m^2$	Plugging rate, %
1	516.1	389.1	24.6
2	610.2	455.2	25.4

2) *Change rate of water phase permeability*

The parameters of artificial core filled with quartz sand are shown in TABLE Ⅴ.

TABLE V. THE PARAMETERS OF ARTIFICIAL CORE FILLED WITH QUARTZ SAND

Parameters	Single tube model 3	Single tube model 4
diameter, cm	2.5	5
length, cm	19	52
Pore volume, mL	15	237.7

The test temperature is 70℃, and the relative permeability correctives injection rate are 2 mL/min and 5 mL/min. The decline rate of water phase permeability is 90.3 % and 95.5% (plugging water rate). The test results are shown in TABLE Ⅵ.

TABLE VI. TEST RUSULTS

NO.	Pemeability before plugging K3, $\times10^{-3}\mu m^2$	Pemeability after plugging K4, $\times10^{-3}\mu m^2$	Plugging rate, %
3	1032.2	100.1	90.3
4	1324.8	60.2	95.5

From above experiments, it can be seen that the relative permeability correctives can plug water effectively, and the sealing rate of oil is very low. Therefore, it can play an effective role in adjusting water phase permeability, and the performances are fit for requirements of selective plugging agent.

Ⅳ. SCREENING AND EVALUATION OF OIL SOLUBLE RESIN

Oil soluble resin is a kind of synthetic material, which has the characteristics of being dissolved in oil, but not in water. It is an ideal material for selective water shutoff agent. Main parameters of oil soluble resin are shown in TABLE Ⅶ. Oil soluble resin has some structural strength itself, and it has the priority to go into the high permeability and high permeability formation. In the process of oil production, oil soluble resin can be dissolved in oil and can not react with water [8]. Depending on the characteristics of oil soluble resin, it can meet horizontal wells selective plugging water requirements. The evaluation were carried out indoor.

TABLE VII. MAIN PARAMETERS OF OIL SOLUBLE RESIN

Items	Parameters
appearance	faint yellow or sandy beige suspension liquid
pH value	6~8
density, g/cm^3	1.0~1.15
solid content, %	≥25

A. *Particle size distribution*

Particle size analysis of oil soluble suspension was carried out by laser particle size instrument. The particle size in 3-8 um of the solid particles accounted for 83% in the oil soluble resin system. It is the main component of the system. A small portion of solid particles is not in the range of the system. More than 8 um accounted for 8%, and less than 3 um accounted for 9%. But the total accounted for less than 20%. In field application, we can select the suitable oil soluble resin according to the actual reservoir characteristics and temperature. Oil soluble resin must be prepared to match with the reservoir pore throat size [9].

B. *Selective evaluation*

In order to investigate the selective sealing ability of oil soluble resin suspension, some experiments are carried out in the laboratory.

Experimental preparation and conditions. The oil soluble resin suspension concentration was 10%, and the system was diluted with water. The experimental temperature was 70 ℃. The cores used in experiment were artificial cores, and No.5 core and No. 6 core were artificial filled with sand. Simulating water was used to drive, whose mineralization was 5000 mg/L. The flooding oil was simulating oil, and the main ingredient is kerosene.

Experiment process [10]. The core was accessed in the process; saturated with water; measured the pore volume; measured the water phase permeability Kw1 after it was stable (agreed for the forward). Then the core was saturated with oil, and the irreducible water saturation was established. Measured the oil phase permeability Ko1. Inject water to water content of 98%; inject 10% concentration of the oil soluble resin suspension 1PV; and inject water forward to flow state stability; measure the water phase permeability Kw2; inject oil forward to flow state stability; measure the oil phase permeability Ko2. From the experimental results, it can be seen that different permeability core plugging rate was more than 96%. Inject oil in the opposite direction, and oil soluble resin dissolved by oil slowly, the permeability recovery value can reach more than 90%, thus oil soluble resin has excellent selective plugging effect.

V. CONCLUSIONS

1) In the horizontal well water plugging field conditions, in order to meet the screen pipe completion requirement, emulsion polymer gel system, the relative permeability correctives and oil soluble resin plugging agent system are screened. And the three systems have strong adaptability, which can satisfy the screen completion for horizontal well selective water plugging requirements.

2) Emulsion polymer gel not only has the performance of temperature resistance, salt tolerance, higher viscosity, but also has some advantages such as dissolved quickly, dissolved completely, and good fluidity, so it is fit for point water exit of horizontal well in heterogeneous reservoir.

3) Relative permeability correctives are changing the wettability of rock surface and increased water flow resistance, and have low viscosity. They are fit for low permeability reservoir.

4) Oil soluble resin has many good characters, such as it can be soluble in oil but not in water, and particle size can be adjusted, and selective plugging performance is good. It is fit for high porosity and high permeability reservoirs.

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