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Weak Gel Flooding Research and Effect Assessment of Horizontal Injection-Production Well Groups in Light Level of Oilfields

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Abstract

Weak gel flooding has been tested and achieved good results in Bohai heavy oilfields. Based on the mechanism analysis and numerical simulation study, weak gel flooding technology is believed to be effect of increasing oil and decreasing water in light oilfields. BZ S oilfield is a low-viscosity oilfield based on horizontal wells development. Due to different production online time and production rate of the well groups of injection and production horizontal wells, it caused advantageous channels formed between injection and production wells in some groups, which reduce storage rate of injection water and affect the development effect. In order to suppress the injected water onrush along the high permeability layer and improve water-oil mobility ratio and sweep efficiency, we have selected two groups for the weak gel flooding test. After flooding test, we evaluate and analyze the recovery and injection characteristics. It shows the test did not achieve the expected result. Therefore, we sum up reasons for the defeat. First, for horizontal injection wells, weak gel plugged well section of relatively pool physical property around water injection wells, increase of wellhead pressure for injection wells make it difficult to meet the requirements of injection allocation. Second, weak gel is hard to work for the pattern of spacing greater than 400m. For these two reasons, weak gel is not displaced and injected to the deep reservoir, and superior channel is still existed, not present precipitation increased the effect of oil wells. Through the evaluation and failure analysis of this displacement test, we proposed technical requirements for weak gel flooding on the horizontal group of injection and production wells. It provided practical experience and references for the other oilfields EOR tertiary oil recovery programs.

Key words: Light oil; Horizontal well; Weak gel flooding; Evaluation; Failure analysis

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INTRODUCTION

The weak gel flooding technology first used on NB X oilfield has been proved to be successful in 2007. After that, we popularized this method on various kinds of heavy oil reservoirs like LD A and QHD B in succession. Eventually, the feedback in those experiments showed that this technology played a certain effect of increasing oil and decreasing water.

Based on the experience of current light oilfields as well as the low-viscosity ones that have already utilized weak gel flooding technology, we initially explored the flooding mechanism and analyzed the numerical simulation, field trials, evaluation of the development effect of weak gel flooding which concerned about the medium and light oilfields offshore based on the horizontal wells development. Ultimately, we obtained some periodical results which provided empirical experience for keep exploring the applicability of weak gel flooding on the medium and light oilfields offshore. Moreover, it offered the mounts of reference data for similar wells and formulating tertiary oil recovery programs.

1. INTRODUCTION ABOUT WEAK GEL FLOODING TECHNOLOGY FIELD EXPERIMENT

1.1 Weak Gel Flooding Technology Adaptation Analyses

BZ S oilfield is an inherited closed fault block whose complexities are due to faults within the reservoir. Belonging to the shallow delta, the mainly oil-bearing formations characterized by high porosity, high permeability are developed from the bottom of Neogene Minghuazhen formation. Formation oil viscosities varied from 8-34mPa·s. Following the principle of using hierarchical system development, this oilfield utilized horizontal wells in a large scale. Specifically, the number of those wells was accounted for 74% of the total number of oil fields. Otherwise, this oilfield has already entered in medium to high water cut period after producing five years of high speed exploitation. Water cut of the whole oilfield has already reached 68%. Furthermore, half of the wells have water cut higher than 60%. Moreover, plane heterogeneity of sand bodies and high production rate of horizontal wells were two aspects that leaded to uneven fluid production of oil wells as well as evident dominant channels which greatly restricted the development of the oil field.

With the aim of expanding the swept area of water flooding, we ascertained that weak gel flooding technology was suitable for BZ S oilfield according to the mechanism (Table 1). Specifically, it illustrated that this could not only improve inhomogeneity in oilfield but also meliorate the mobility ratio in order to increase the areal sweep efficiency, volumetric conformance efficiency and the recovery ratio.

Table 1
Contrast of Selecting Parameters Between Chemical Flooding Reservoir and BZ S Oilfield in EOR

Selecting parameters	Standard in selecting technology	BZ S oilfield
Rock types	**Clastic rock**	**Sandstone**
Oil layer thickness, m	Single layer effective thickness is bigger than one	12
Reservoir temperature, ℃	<75	55
Permeability, mD	>50	1,700
Permeability variation coefficient	0.4-0.8	0.8
Formation crude density, g/cm^3	<0.9	0.902
Formation crude density viscosity, mPa·s	<100	8-34
Formation water mineralization, mg/L	<10,000	<10,000

1.2 Researches of Reservoir Engineering Plan on Weak Gel Flooding

Principles of selecting weak gel flooding experimental well groups: Firstly, well groups should be representative. In other words, they should be capable of representing the geological reservoir characteristics of BZ S oilfield. Secondly, desired well groups were supposed to possess more monitoring materials. Thirdly, reservoir quality as well as correspondence between injection and production of desired ones ought to be in better condition. Last but not least, they should be more independent which means less effect upon perimeter wells. Only NmⅡ-1167 sand body was fulfilled due to the active edge water of BZ S oilfield, because of which, we eventually ascertained that well groups A27H and A42H were the chosen ones. Horizontal well group A27H's injection withdrawal ratio was 0.5 while A42H was 1.

Designing of Weak gel flooding program: Based on the history matching results of these two well groups and the experimental data, we have taken advantage of numerical simulation to assure weak gel injection parameters in reasonable scope. Ultimately, we obtained viscosity-concentration curve, polymeric compound adsorption curve, calculation of pore volume that could not be affected and dilution shearing curve. On the basis of achievements above, we started performing researches on parameter optimization of weak gel flooding injection. Moreover, according to the analysis of sensitivity, we confirmed best injection parameters as shown in Table 2.

Table 2
Best Injection Parameters Figure

Well group name	Polymeric compound, mg/L	Concentration slug size, PV	Injection speed, PV/a
A27H	1,200	0.062	0.066
A47H	1,400	0.056	0.071

On account of optimum programs above, we have made predictions of experimental well groups' weak gel flooding effects. In addition, as the flow simulation diagrams are shown beneath (Figures 1, 2), just before weak gel flooding, flow streamlines between production and injection wells were focussed and distributing uneven. Moreover, the oil saturation had a lower value which testified that injected water mostly flows along high permeability percolation paths. After weak gel flooding process, we sealed those paths. It turned out that flow streamlines between the two well groups became distributing evenly. Additionally, conformance effect had been improved. Indices predictions are shown in Table 3.

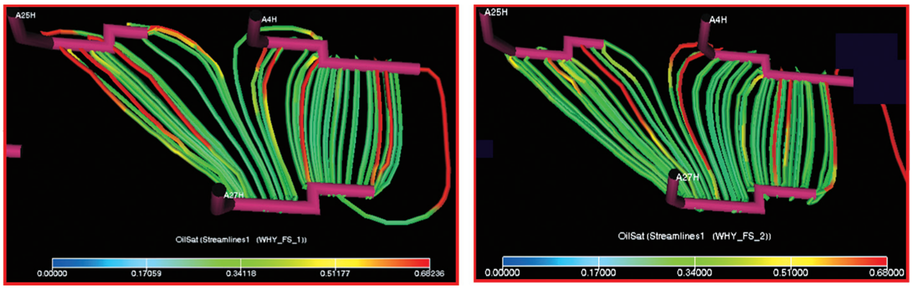

Figure 1
Flow Streamlines Comparison Between Water Flooding and Weak Gel Well Flooding in Well Group A27H

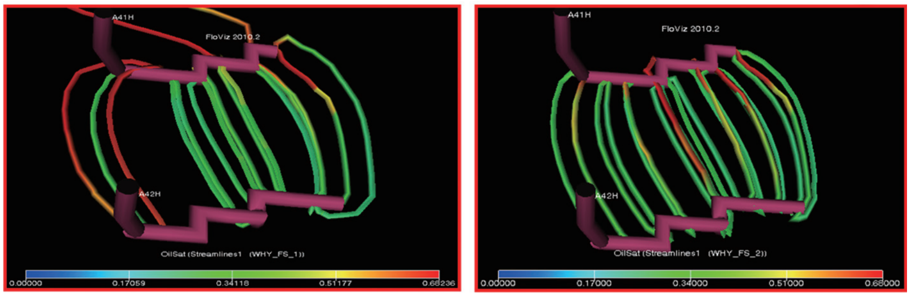

Figure 2
Flow Streamlines Comparison Between Water Flooding and Weak Gel Well Flooding in Well Group A42H

Table 3
Experimental Well Group Indices Predictions

Well group name	Maximum decrease in water cut, %	Average daily oil increase, m^3/d	Progressive increasing oil, $10^4 m^3$	Recovery ratio enhancement, %
A27H	23	35.1	2.63	1.2
A47H	14	6.7	1.42	1.8

1.3 Introduction About Weak Gel Flooding Technology Field Implementation

Experimental well groups A27H, A42H have been implemented weak gel flooding technology since 2012.10. There were two stages which lasted a year and a half. To put this in perspective, in the process of the implementation of the weak gel injection, the concentration and viscosity of the two polymer injection wells were basically following the requirements of the reservoir project design. In the first phase of the project, the concentration of main slug in well group A27H was 1200mg/L which lasted for180 days. While in the second phase, the concentration was 1200mg/L and lasted for 113 days. The numbers of well group A42H in first phase were 1400mg/L and 180 days and in phase 2 were 1400mg/L and 119 days respectively. Meanwhile, for the sake of making sure the weak gel flooding program would proceed smoothly, we strengthened the dynamic monitoring as well as the reservoir engineering researches.

2. EVALUATION OF WEAK GEL FLOODING DISPLACEMENT EXPLOITATION CHARACTERISTICS

Before well group A27H had been implemented weak gel flooding technology, two oil wells within it had different water ratios, among which well A4H was 80% while A25H had the number of 20%.Obviously, uneven water flooding problem was pretty serious. At the same time, because of horizontal water injection wells having strong injection capability, formation pressure of this well group remained around the bubble point and water injection well A27H's well head pressure was below 4MPa. Moreover, before well group A42H had been implemented this technology; oil well A41H within the group had a water ratio of 80%. Clearly, there existed an evident water channeling, and it was convinced by the tracer. Formation pressure of this well group appeared around the initial pressure and water injection well A42H's well head pressure was below 7MPa. Afterwards, being impacted on the dynamic understanding of well group polymer injection experiments as well as comprehending polymer flooding laws of BoHai oilfield and other onshore oilfields that had already taken this method, we made assessments of weak gel flooding displacement exploitation effect.

2.1 Evaluation of Injection Characteristics

(a) Evaluation of injection pressure characteristics: injection pressure change is one of the earliest characteristics of injection well in polymer flooding process. Before injecting weak gel, wellhead pressure of these two wells varied from 4 to 7MPa.While transforming to inject polymer, wellhead pressure rose to 7-9MPa which means 5.7-8.2 times higher than before. On the contrary, BoHai oilfield and other onshore oilfields normally grow 1.2-1.5 times which mean the former multiple is too large.

(b) Evaluation of apparent water injection indices characteristics: apparent water injection indices of water injection wells that transformed to polymer afterwards mostly showed a downward trend due to the elevated injecting pressure. Before weak gel flooding, the average water injection index of well A27H was 540m^3/(d×MPa×m). While after flooding, this index turned to 60m^3/(d×MPa×m). The declining rate was 89%. Meanwhile, in the case of well A42H, the former index was 350m^3/(d×MPa×m) while the latter was 40m^3/(d×MPa×m), the declining rate of which was 89%. Compared with LD A oilfield which has already implemented weak gel flooding method that has a declining rate of 70%, our case has a too much bigger absorbing capacity after flooding.

(c) Evaluation of filtration resistance characteristics: confirming by the Hall curve, the resistance coefficient is normally used to describe the ascending of filtration resistance within the reservoir. Besides, the Hall curve means that relationship between cumulative injection and pressure is linear by a rectangular coordinate system. When the injection material transforms from water to polymer, this curve experiences some deflection. Slope ratio of the polymer injection phase and the water injection one is the resistance coefficient, the increase of which explains the reason why subsurface fluid flow speed becomes slower and a change of direction thus expands the area of swept volume. Moreover, calculation showed that the resistance coefficient of well A27H in the first stage was 6-9 afterwards polymer injections while in stage two was 5. Besides, the residual resistance factor was 8(as is shown in Figure 3). Calculation showed that the resistance coefficient of well A42H in the first stage was 6-12 afterwards polymer injections while in stage two was 7. Besides, the residual resistance factor varied from 7 to 11 (as is shown in Figure 4). In addition, after injecting weak gel, the average resistance coefficient of LD A oilfield was 5 approximately. Flooding was existed certain plugging effect on high permeability channels, compared with this oilfield.

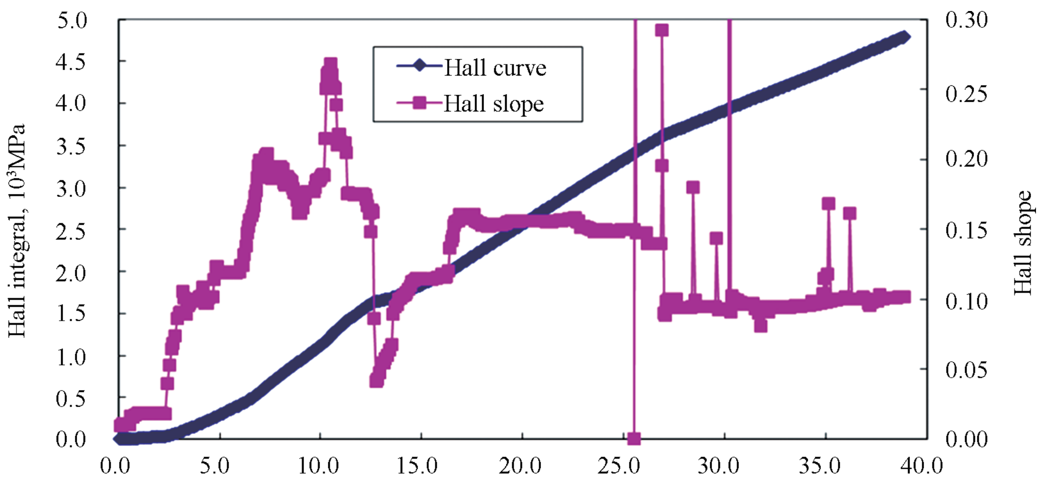

Figure 3
Hall Curve of Well Group A27H

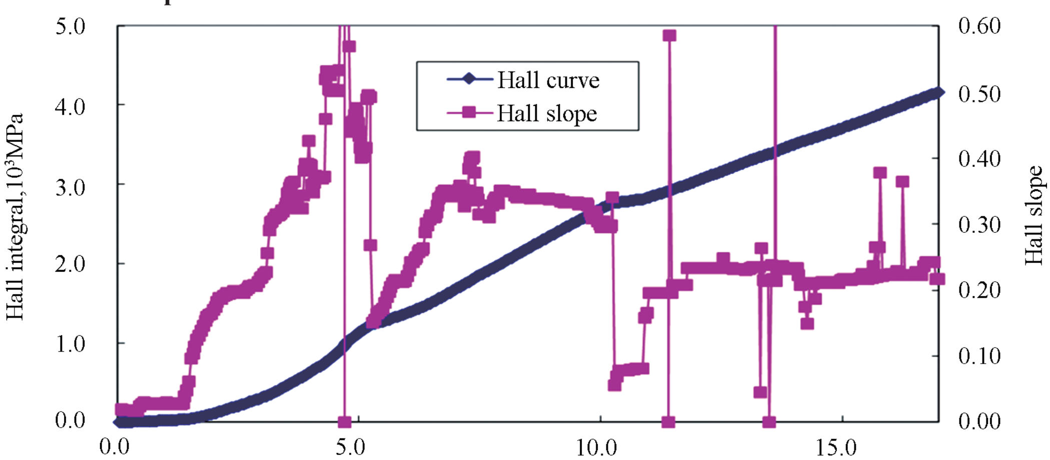

Figure 4
Hall Curve of Well Group A42H

(d) Evaluation of injection profile characteristics: Injection profile test is the most direct method to observe the change of absorbing capacity before and after polymer injection. According to the injection profile tests of these two horizontal injection wells before and after gel flooding, we obtained the results that presented relatively concentrated water absorption spots of horizontal section. With the length of four hundred meters, the horizontal section's effective water absorption length was below one hundred meters. Obviously, there existed a huge gap between results and our design.

2.2 Evaluation of Production Characteristics

There exists plenty of methods to evaluate production characteristics, such as methods of net added oil measurement、net decrease water measurement as well as decline rate curve observation. However, the application of these kinds of methods are premised on satisfying the demands of reasonable injection allocation which allows well groups' formation pressure maintaining at the same level before injecting polymer. After injecting polymer in BZ S oilfield, there appeared a sharp rise in wellhead pressure of water injection wells. Confined by safety injection pressure, water injection wells could not meet the initial design. In terms of well group A27H, before polymer injecting, the designed injection allocation was 1,000m^3/d. Even though we implemented twice acidifications after polymer injection, the maximum injection volume could only reach 600m^3/d. Moreover, same phenomenon occurred in well group A42H as well. From the perspective of the production performance in oil wells, oil well A25H from group A27H, presented a phenomenon of decreasing production fluid and degassing after polymer injection. At the same time, due to the severe situation of a lack of injection, oil wells produced quantity of sand which restrained the productivity of oil wells. Well group A42H also showed a similar situation. Therefore, the effect of optimizing displacement cannot be accomplished unless satisfying the injection allocation rate.

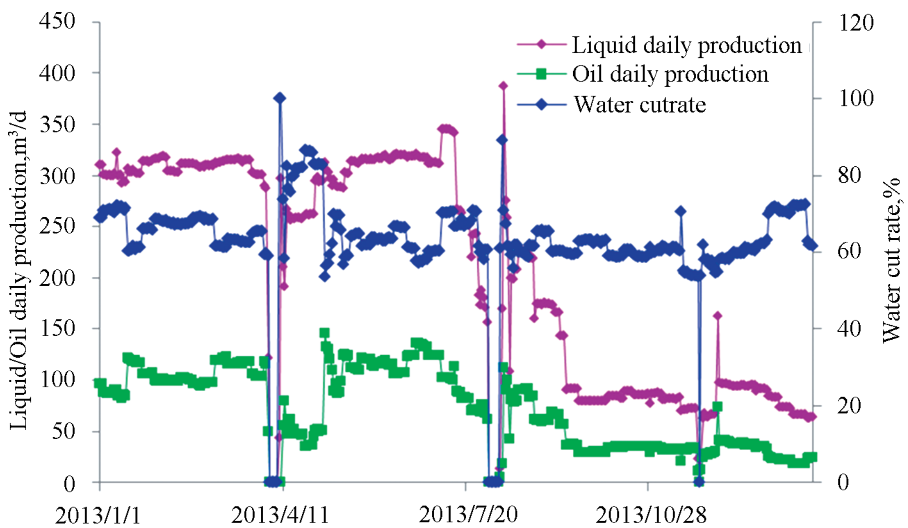

Figure 5
Production Curve of Well A25H

2.3 Analyzing Reasons of Failure

Based on the analyses above concerning about development results of production and injection wells after displacement adjustment, we arrived at a conclusion that the experiment of these two well groups in BZ28-2 south oilfield appeared to be a failure. There existed three main reasons: Firstly, high levels of injection pressure that affected water injection quantity was the key factor that leaded to this failure. This was related to the well type of horizontal water injection wells. Normally, horizontal water injection well had bigger water injection rate. Furthermore, it was awfully difficult to realize water absorption uniformly due to the long well section as well as greater heterogeneity in the reservoir along the horizontal section. Moreover, weak gel plugged well section of relatively pool physical property around water injection wells .Thus, conformance efficiency in deep reservoir had not been enhanced. Secondly, stabilities of weak gel in reservoir became lower while increasing the well spacing. However, the speed of injection is decreasing. Meanwhile, the longer weak gel would stay in oil reservoir, the bigger possibility and quantity of viscosity of the solution decrease would happen. Consequently, it is difficult to apply weak gel in pattern well spacing larger than 400m.

SUMMARY AND SUGGESTIONS

(a) After researching the displacement adjustment mechanism and numerical simulation, we arrived at a conclusion that weak gel flooding was feasible in BZ28-

2 south oilfield. It is an effective way to improve recovery by 1.2%-1.8%.

(b) Lasting for almost one year, field tests on two well groups show that the function of gel mainly concentrated around the water injection wells. However, superior channels in deep reservoir have not been improved. Moreover, effects of water precipitation reduction and oil increment have not been achieved either.

(c) Learning from this failure, we put forward two suggestions: firstly, it's better to implement profile modification before adjusting displacement on horizontal water injection wells; secondly, with regard to pattern well spacing larger than 400m, weak gel flooding can hardly work. We should carry out displacement adjustment after thickening well pattern thus will have good actual effects.

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