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Experience from Polymer-EOR on Offshore Heavy Oil Field in Bohai Bay, China

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Abstract

In this paper, a review work based on the polymer flood for offshore heavy oil reservoir is presented. In recent years, the CNOOC has launched quite a few chemical EOR projects at offshore oilfields in the Bohai Bay, China. With the useful life of platform and the present production state, polymer flooding is considered and already proved as an important technology for the strategic development of offshore heavy oil fields in the Bohai Bay. Up to 2010, there were three polymer-EOR projects on heavy oil field with the water cut between 10 and 80%. And about 20,000 tons polymer powder was used in 27 wells in the past 5 years. It has been seen that the water cut declined while the oil production increased. The application result shown is feasible. The procedure of polymer injection is presented in this paper.

Keywords: *polymer flood, offshore oilfields, water cut, oil production*

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INTRODUCTION

About 60–70% oil remains in the formation after water flooding, and for offshore heavy oil reservoir, more oil (about 80%) remains by the end of the platform life [1–3]. How to produce the remaining oil economically and efficiently has become a problem to be resolved. For onshore oilfield, for example Daqing oilfield, the industrial scale polymer flooding was started in 1996 [4]. The timing of polymer injection on onshore oilfield was at the stage of high and ultra-high WCT (above 90%). And it was obtained of the high incremental recovery (about 10% OOIP) [5].

To obtain the maximum recovery factor in the life of platform, the polymer flooding tests ware started. From 2003 to now, polymer flooding was conducted from the single well-to-well pattern pilot test, and to integrated oilfield, extending the test scale step by step. By 2010, there were 27 polymer injection wells in five platforms of three oilfields: the single well injectivity pilot test started on PF-A oilfield in 2003, the well pattern pilot test on PF-A oilfield in 2005, polymer flooding test for low WCT oilfield of PF-B in 2006 and for mid-high WCT oilfield of PF-C in 2007, and then enlarged scale field test on PF-A oilfield in 2008. With the development of polymer flooding on offshore oilfield, the effects on water cut reduction and oil production improvement were obtained. The total oil production improvement was more than 6.0 million barrels by the end of 2010.

POLYMER FLOODING TECHNOLOGIES

Generally, the reservoir conditions of offshore oilfields had characteristics of thick pay zone, multi-layer, serious heterogeneity, viscous oil, high salinity of brine (calcium and magnesium content: 500–900 mg/L) and were developed with big well space (350–600 m) anti-9-spot well pattern. And there were the limited platform space and life span of facilities (20–25 years). For more oil produced, EOR by polymer flooding was considered as an important technology for the strategic development of offshore heavy oil fields in the Bohai Bay.

The polymer flooding offshore heavy oil faces on the following:

- Low viscosity of polymer solution in high salinity and hardness of make-up brine;

- Hard to satisfy the requirement of injection facilities due to the limited platform space;
- Hard to conduct on-line produced fluid treatment on platform; and
- Hard to develop the evaluation method for early polymer flooding.

Based on the polymer flooding achievement on onshore oilfields and the development characteristics of offshore oilfields [5, 6], it was developed of the novel polymer flooding technologies including:

- Displacement agent: salt tolerant, anti-mechanical degradation, multi-functional, high-efficient, long-term stability, and low cost;
- Injection facilities: small, skid-mounted, fast dissolving;
- Produced fluid treatment technologies: fast, qualification without re-treatment, sewage reinjection;
- Effective evaluation methods: establishment and verification of early injection evaluation method.

Field Application

Reservoir Screening and Target Oilfields

Table 1 shows the reservoir screening criteria [5]. Based on the criteria, three oilfields including PF-A, PF-B and PF-C, were chosen for polymer flooding test. Table 1 shows the key reservoir condition of the target oilfields which were located in the Liaodong Bay basin.

Table 1: *The Screen Criteria and Target Oilfields.*

Item		**Screen criteria**	**PF-A**	**PF-B**	**PF-C**
Formation oil viscosity, mPa.s		< 200	30–450	10–20	10--30
Permeability, mD		＞10	100–10000	1000–4000	100–5000
Well pattern			anti 9-spot		
Well space, m			350–400		
Formation temperature (℃)		＜93	50–70		
Formation water (mg/L)	Salinity	＜100000	6540–20000	2873	3000–6500
	Divalent cation	＜500	30–800	10	13
Water source mg/L	Salinity		8000–10000	8000–10000	1500–3000
	Divalent cation		600–900	500–800	80-100
WCT,%			50–60	< 10	70–80

PF-A oilfield, which reservoir oil viscosity is from 30 to 450 mPa.s, was a typical heavy oil field in Bohai Bay where lots of heavy oil fields were found. There are ten platforms set to develop the oilfield, one of the biggest oilfields found in the Bohai bay, which the water cut is about 60% after around 10 years development by water flooding. After lab research, several key technologies of polymer flooding on offshore heavy oil field were achieved, and then the field pilot has been implemented successfully in PF-A oilfield since 2003. At present, there are 13 wells injected with the hydrophobically associated polymer solution. The polymer flooding development plan on overall oilfield has been achieved to implement novel development model of offshore heavy oilfield from EOR technology. Meanwhile, the polymer flood technology was applied in PF-B and PF-C oilfield in Bohai Bay in the past 3 years. And the three oilfields' production was increased about 6.0 million bbl oil by the end of 2010.

Single Well Injectivity and Well Pattern Pilot Test

The single well injectivity pilot test was conducted from 2003 to 2005 in PF-A oilfield which reservoir is a high oil viscosity and high salinity oilfield. And then the well pattern pilot test was carried out using a polymer slug of 0.172 PV with 1750 ppm polymer concentration from 2005 to 2008 in the same oilfields [7]. The increase of water cut was effectively controlled after polymer flooding. And the effect of incremental oil production was obtained.

Enlarged Scale Field Test (Medium WCT: 40–60%)

For achieving scale effect of polymer flooding, the test was enlarged by transferring external water injection wells to polymer injection wells after finishing the well pattern test in PF-A oilfield in 2008. The run was carried out using a polymer slug of 0.3 PV with 1750 ppm polymer concentration. It was forecast that the incremental recovery is 7.6% OOIP, by simulating the process.

Up to end of 2010, the 13 injection wells were transferred to polymer injection wells and the total amount of polymer solution injected after the test is about 0.09 PV. Figure 1 shows the WCT history after polymer flooding and the simulated water flooding. The actual WCT was about 58% before polymer flooding and it increased to 68% when started the enlarged scale field test. The WCT of test area was kept about 70% with more than 2 years polymer flooding and decreased recently. By comparison with the simulated water flooding, it can be seen that the polymer WCT was about 10 factor lower than the water oil production rate based on the precondition that both run with the same liquid production rate.

Figure 2 shows production rate history after polymer flooding and the simulated water flooding. By comparison, it can be seen that the polymer oil production rate was higher than the water oil production rate based on the precondition that both run with the same liquid production rate. The oil production rate increased remarkably because the infilled wells were put into production. It encountered with some problems in the process of polymer injection. Measures such as enhancing polymer concentration of central block from 1750 ppm to 2500 ppm were taken to decrease water cut of the wells. On the other hand, output polymer concentration decreased. Those measures effectively postponed water breaking through and ensured good effect of polymer flooding test.

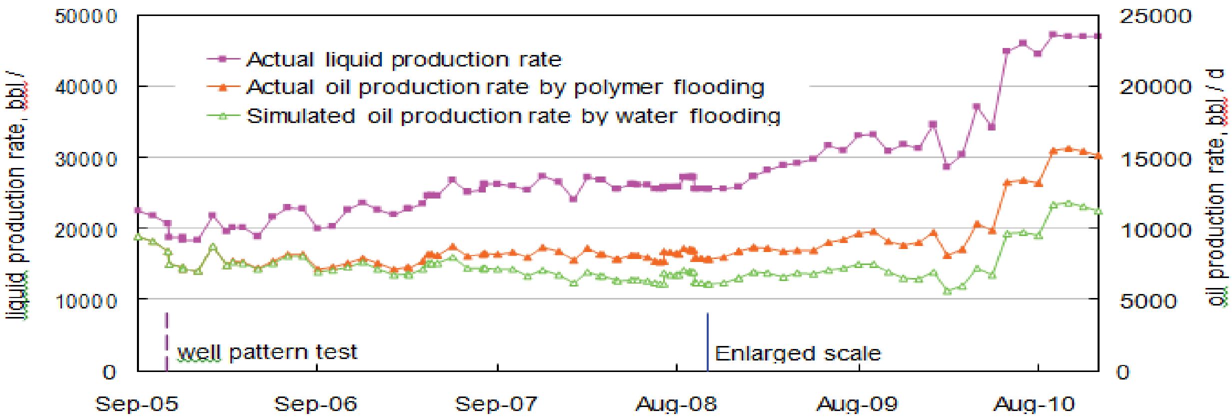

Fig.1: *Production Rate History After Polymer Flooding of PF-A Test Block.*

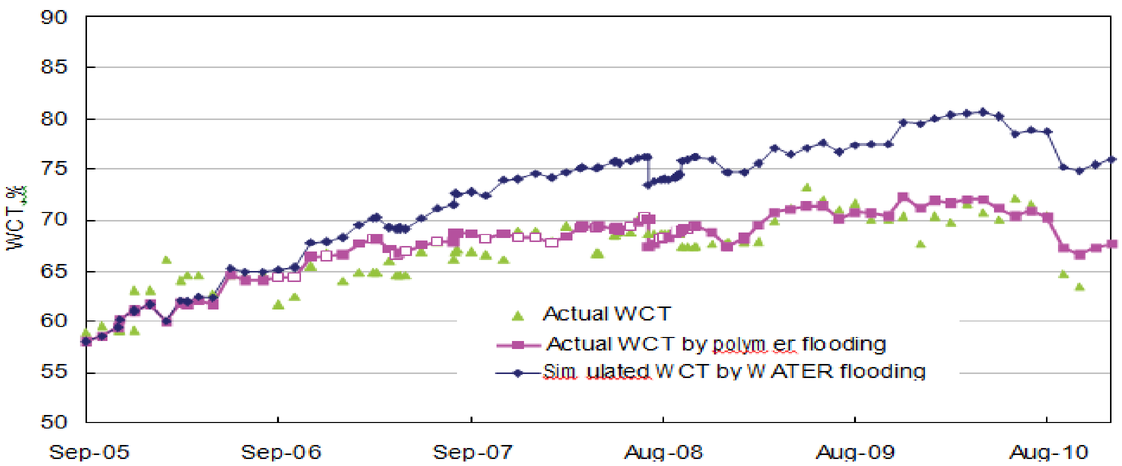

Fig. 2: *WCT History after Polymer Flooding t of PF-A Test Block.*

Field Test of Polymer Flooding for Low WCT Oilfield (WCT < 20%)

For probe novel model to develop effective offshore, the early polymer flooding was introduced to the development of offshore oilfields. It was chosen as the test oilfield of PF-B which was put into production in 2005. The run was carried out using a polymer slug of 0.16 PV with 1600 ppm polymer concentration since 2006. It was forecast that the incremental recovery is 6.1% OOIP, by simulating the process.

Up to the end of 2010, all injection wells were transferred to polymer injection wells and the total amount of polymer solution injected after the test is about 0.11 PV. Figure 3 shows the production history, both actual development and the simulated water/polymer flooding. It shows that the WCT increased after polymer flooding, even the decrease did not appear over more than 4 years of polymer injection. The key is the timing of polymer flooding. For the early polymer flooding, the water cut curves shapes differ greatly from high and ultra-high water oilfields such as onshore oilfields. How to evaluate the effect of the early polymer flooding was the novel issue for polymer flooding of offshore oilfield. At present, the applied method is reservoir numerical simulation.

By comparison with the simulated water flooding, it can be seen that the polymer WCT was lower than the water oil production rate and the polymer oil production rate was higher than the water oil production rate based on the precondition that both run with the same liquid production rate.

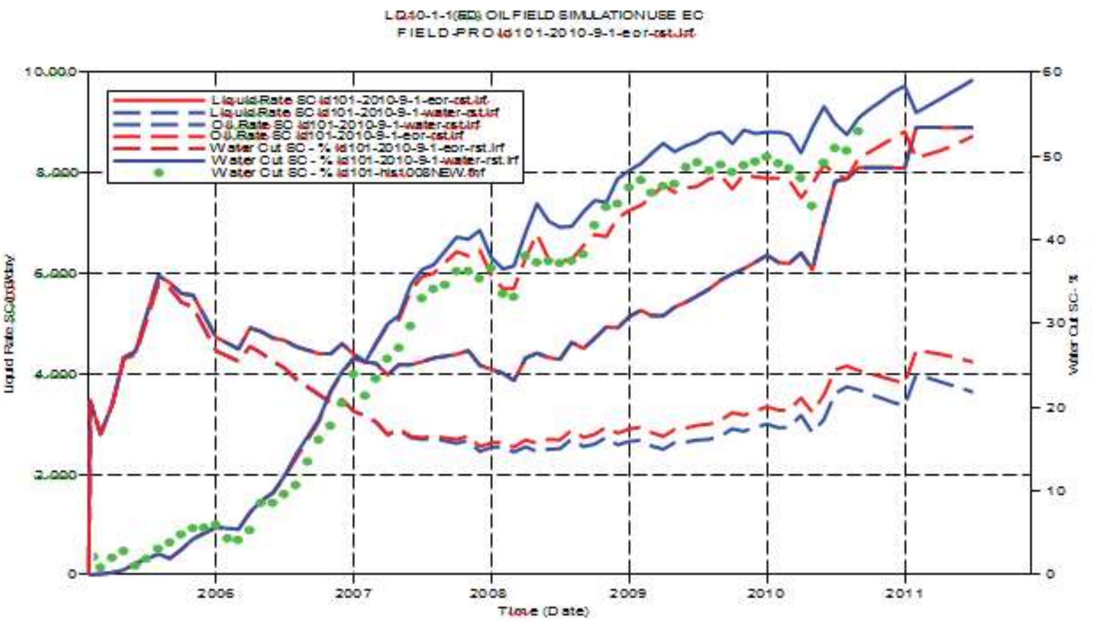

Fig. 3: *Production History of PF-B.*

Field Test of Polymer Flooding for Med-High WCT Oilfield (WCT: 60–80%)

Water salinity was one of the most important factors for polymer flooding. The PF-C oilfield was considered as the best candidate for polymer flooding which it had the lowest water salinity in Bohai Bay. The run was carried out using a polymer slug of 0.23 PV with 1200 ppm polymer concentration since 2007. It was forecast that the incremental recovery is 6.2% OOIP, by simulating the process.

The polymer flooding was initiated in 2007 in the oilfield which the WCT was 70–80%. Up to the end of 2010, all injection wells were transferred to polymer injection wells and the total amount of polymer solution injected after the test is about 0.13 PV. Figure 4 shows the production history of one of the center wells. It can be observed from this figure that water cut increased after polymer flooding and reached the maximum value of 78%. With the polymer injected, the water cut decreased by a maximum of about 30% while oil production rate increased from 300 to 450 bbl per day.

Figure 5 shows the production history of the target block. It can be observed from this figure of the similar rule as the typical center well which the water cut increased after polymer flooding and reached the maximum value of 80%. With the polymer injected, the water cut decreased by a maximum of about 10 to 70% while oil production rate increased by about 30%.

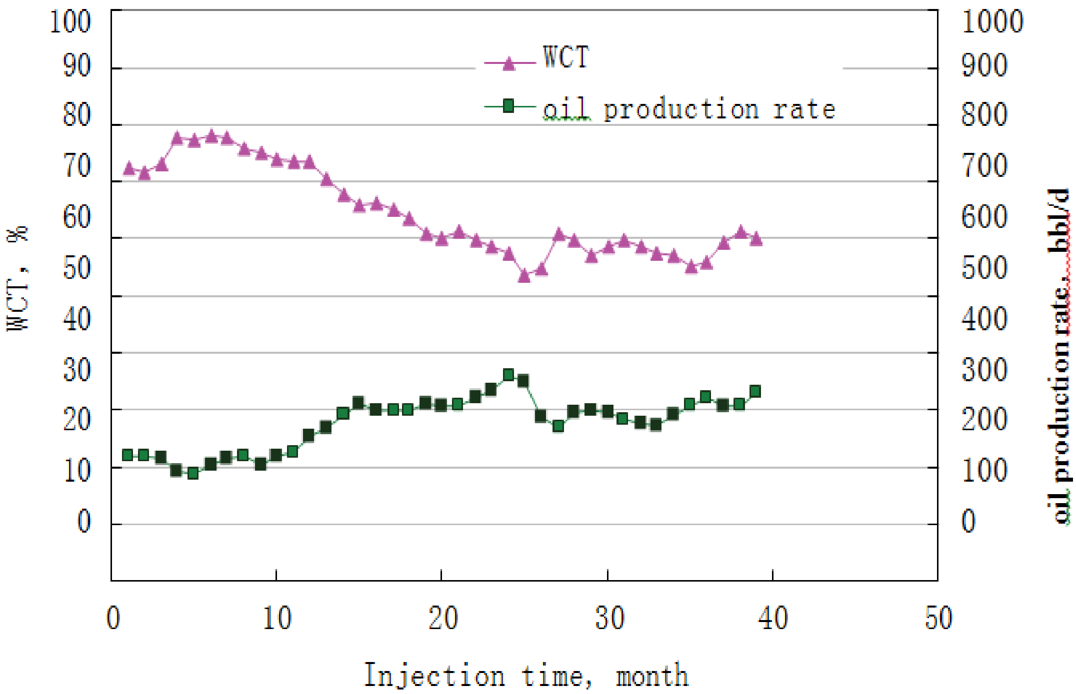

Fig. 4: *WCT and Oil Production Rate Typical Center Well of PF-C.*

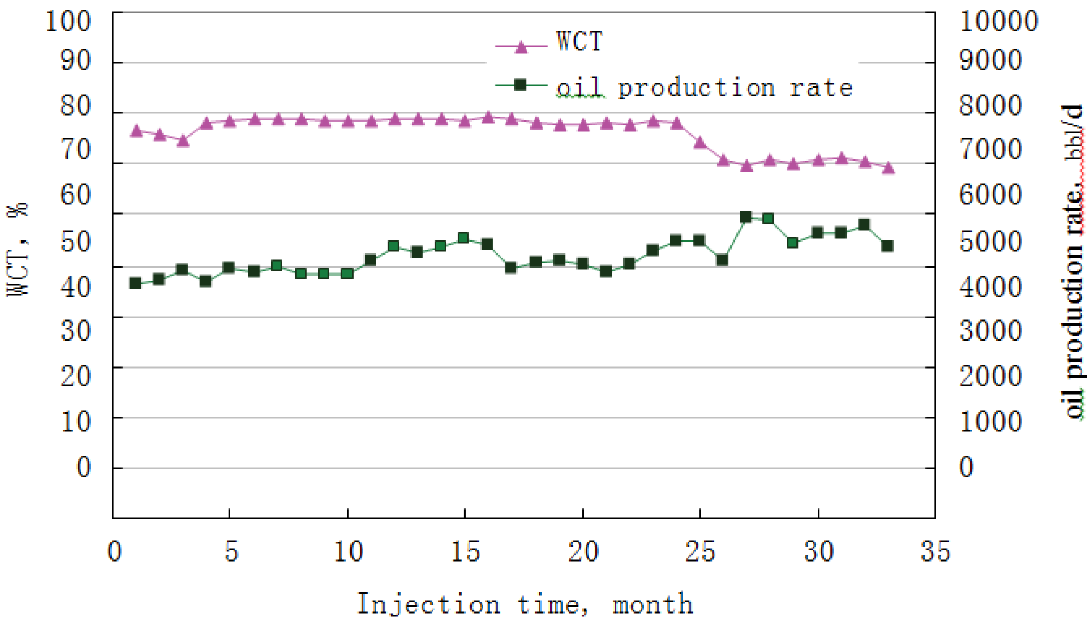

Fig. 5: *WCT, Oil Production Rate of PF-C.*

CONCLUSIONS

1. The polymer flooding technology system for offshore oilfields has been achieved including displacement agent, injection system, reservoir evaluation, etc.
2. It decided the WCT curves shapes of the timing of polymer flooding, and it was not inevitable of the typical WCT funnel of polymer flooding on onshore oilfield.
3. Polymer flooding for enhanced offshore oil has been proved successful for Bohai oilfield, and it can be applied to more oilfields.

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