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Research and Practice of the Early Stage Polymer Flooding on LD Offshore Oilfield

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Abstract

Literature survey shows that polymer flooding was generally conducted during high water-cut stage (WCT>80% to 90%). Even the first China Offshore polymer flooding project was carried out in SZ when water cut was 60%. By then, conduction of polymer flooding in early phase (WCT<10%) was just discussed in theory. For offshore oilfield, the treatment of water could be costly. Because polymer improves mobility ratio of replacement fluid over oil and sweep efficiency, less water is injected and less water is produced. So, we did enormous research about the polymer flooding on early stage by theoretical analysis, series of experiments and chemical flooding simulation. Based on these researches, we carried out the first field test of polymer flooding on early stage in LD. Single well polymer injection test was started in Mar 2006 when the water cut in the pattern was lower than 10%. After the trial, there were other 5 water injectors being converted to polymer injectors from 2007 to 2009. The polymer flooding controlled reserve was about 25,250,000 m^3. For the early stage polymer flooding, the characteristics of the responses on producers were different from the case in which polymer flooding was conducted during high water cut stage. The water producing of the producers continued to rise up after polymer flooding, but the simulation research showed that the water cut increasing rate was lower than the rate during merely water flooding. In addition, we observed the drop-down on the water cut in some wells, such as A11, A12, A13, A15, etc. For the well A11, the highest water cut reduction reached 41% after the injectors (A5/A10) profiles controlled, and net incremental oil for A11 even reached 154,510 m^3. By Dec 2014, the total incremental oil by polymer flooding was about 754,650 m^3, and the stage oil recovery efficiency was enhanced by 3.0%. The polymer flooding is still effective, and we will get more oil from the polymer flooding.

Keywords: EOR; Polymer Flooding; Offshore oil field

Abbreviations: RRF: Residual Resistance Factor; RF: Resistance Factor; PORFT: Accessible Pore Volume; FREQFAC: Reaction Frequency Factor; ADMAXT: Maximum Adsorption Capacity; ADRT: Residual Adsorption Level; PI: Pressure Index; WCT: Water Cut.

Introduction

With the improvement of offshore exploration extent, there are more and more heavy oil found. The oil recovery was only 18% to 25% by the conventional oil production method of water injection. So more challenges rise up, such as how can we get more oil? How can we improve the oil recovery? For the offshore oilfield, a method which can be used to develop oilfield more efficiently must be found due to the life time of offshore platform is limited (with the life of 25 years to 30 years).

Polymer flooding was already a mature set of technology to improve oil recovery on the onshore oilfields in China. Literature survey shows that polymer flooding was generally carried out during high water-cut stage (WCT > 80% to 90%). Even the first China Offshore polymer flooding project was carried out in SZ when water cut was 60%. By then, conduction of polymer flooding in early phase (WCT<10%) was just discussed in theory. So, we did enormous research about the polymer flooding on early stage by theoretical analysis, series of experiments and chemical flooding simulation, as shown in (Figures 1 and 2). Gel flooding technology combines the function of improvement of mobility ratio by polymer flooding and injection profile control by cross linked gel injection.

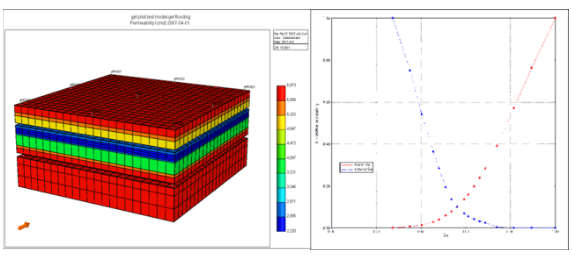

Figure 1: The numerical simulation of the mechanism research.

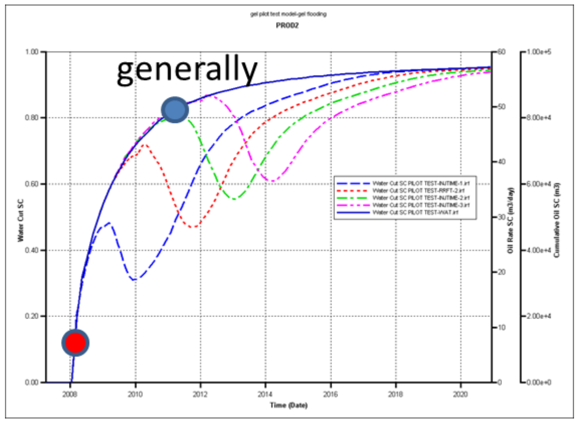

Figure 2: The EOR in different time.

LD oilfield is located in Bohai Bay, characterized by huge thickness,

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Method of displacement	The water cut start to the polymer injection (%)	Viscosity of the oil (cp)	Polymer concentration (mg/l)	Core size	Other lab test conditions
Polymer	0	70	1750	L: 30 cm W: 4.5 cm H: 4.5 cm	Temperature: 65°C Rate of displacement: 1 m/d Polymer injection PV: 0.25 PV
	28				
	53				
	97				
Water	--				

Table 1: The geometric parameters of the model.

Method of displacement	The water cut start to the polymer injection (%)	The water flood recovery before polymer flood (%)	The ultimate recovery factor (%)	Improve oil recovery by polymer flooding (%)
Polymer	0	0	51.35	6.23
	28	22.2	51.08	5.96
	53	23.1	50.75	5.63
	97	45.1	50.35	5.23

Table 2: The results of lab test experiments.

The water cut start to the polymer injection (%)	0	20	40	60	80
Rw (%)	39.86				
Rp (%)	49.28	48.98	48.73	48.3	46.71
ΔR (%)	9.39	9.09	8.84	8.42	6.82

Table 3: Statistical recovery efficiency in the development of 30 years.

The polymer					
Polymer concentration (mg/L)	500	700	1000	1200	1500
Polymer viscosity (cp)	3.5	4.5	6	8	9.5
The cross-linked polymer (P: Cr³=60:1)					
Polymer concentration (mg/L)	500	700	1000	1200	1500
Polymer viscosity (cp)	3	4	5.5	7	8.5

Table 4: The relationship between viscosity and concentration of gel and polymer.

Polymer concentration (P: Cr³)	Viscosity of the crosslinked polymer (cp)				
	Initial	After 2 days	After 5 days	After 10 days	After 15 days
1200 mg/L, (P: Cr³=40:1)	8.2	420	582.3	613	602.3
1200 mg/L, (P: Cr³=60:1)	8.1	312	452.3	523	572.3
1000 mg/L, (P: Cr³=60:1)	5.9	62.9	87.5	137	210.5
1000 mg/L, (P: Cr³=40:1)	6.2	154	231.4	336	341.2

Table 5: The viscosity of the cross-linked polymer.

Core number	Kg ('10⁻³ mm²)	Displacement system	RF	RRF
R3-9	1350	The crosslinked polymer Cp=1200 mg/l (P: Cr^{3+}=20:1)	45.6	58.2
12-4-5	1355	The crosslinked polymer Cp=1200 mg/l (P: Cr^{3+}=40:1)	39.9	48.4
12-3-5	1360	The crosslinked polymer Cp=1200 mg/l (P: Cr^{3+}=60:1)	34.9	39.3
L12-1-1	1345	The crosslinked polymer Cp=1200 mg/l (P: Cr^{3+}=80:1)	32.9	35.6
12-4-2	1320	The crosslinked polymer Cp=800 mg/l (P: Cr^{3+}=20:1)	38.9	46.7
12-3-4	1380	The crosslinked polymer Cp=800 mg/l (P: Cr^{3+}=40:1)	33.9	42.9
L12-1-2	1346	The crosslinked polymer Cp=800 mg/l (P: Cr^{3+}=60:1)	29.9	36.3
12-4-10	1368	Polymer Cp=800 mg/l	12.9	1.8
12-4-10	1349	Polymer Cp=1000 mg/l	16.2	2.5
12-4-13	1342	Polymer Cp=1200 mg/l	21.3	3.2

Table 6: The RF and RRF of the cross-linked polymer.

high permeability, severe heterogeneity, high crude oil density (0.947 g/cm^3) and medium oil viscosity (7.2 cp to 19.4 cp). LD oilfield was put online in January of 2005, and started to inject water on September of 2005. Based on well understanding of the mechanism and effect of the early polymer flooding, we carried out the single well polymer injection pilot test from 2006 when the water cut in the pattern was lower than 10%. After the trial, there were other 5 water injectors were converted to polymer injectors from 2007 to 2009. The polymer flooding controlled reserve was about 25,250,000 m^3. For the early stage polymer flooding, the characteristics of the responses on producers were different from the case in which polymer flooding was conducted during high water cut stage. The water producing of the producers continued to rise up after polymer flooding, but the simulation research showed that the water cut increasing rate was lower than the rate during merely water flooding. Of course, we also observed the drop down on the water cut in some wells, such as A11, A12, A13, A15, etc. For the well A11, the highest water cut reduction reached 41% after the injectors (A5/A10) profiles controlled, and net incremental oil for A11 even reached 154,510 m^3. By December 2014, the total incremental oil by polymer flooding was about 754,650 m^3, and the stage oil recovery efficiency was enhanced by 3.0%. The polymer flooding is still effective, and we will get more oil from the polymer flooding.

Experiment Tests and Polymer Flooding Scheme Design

Mechanism study on early stage polymer flooding

Geometric size of the core model is 30 cm × 4.5 cm × 4.5 cm, and the parameters of experiments were shown in Tables 1 and 2). The results of lab test experiments were shown in Table 2. From the results of the lab test, the difference of the EOR between cases in which polymer flooding conducted at different time was not obvious. But for offshore oilfield, the platform life was about 25 years to 30 years. We must produce more oil in limited time. From numerical simulation of the mechanism research, we know that the larger enhanced recovery value can be obtained, if polymer can be injected earlier (Table 3) [1-3].

Experiment tests and mechanistic models of gel

The relationship between viscosity and concentration of gel and polymer in early stage was shown in Table 4. The experiment about the crosslinked polymer viscosity in the case of different polymer concentrations and ratios of the polymer to Cr^{3+} was done. As is shown in the Table 5, the viscosity also increased with time going by. The results of RF and RRF test were shown in Table 6. RRF of the polymer is 1.8 to 3.2 from the experiment, and the gel is 39.3. According to the experiment results and the SZ oilfield mature experience, RRF of LD gel is 5, and the polymer is 2.5. The static adsorption and dynamic adsorption tests were shown in Tables 7 and 8.

Injection scheme design

The size of injection slug was 0.163 PV, and the period of the slug injection was 5 years as shown in Table 9. Injection system was the polymer and Chromium ion (Cr^{3+}) crosslinking agent. The concentration of the polymer was 1200 mg/L (Polymer: Cr^{3+}=600:1-60:1). The polymer injection rate was 0.033 PV per year. The predicted improve recovery factor was 6.1%.

The Result of the Field Test

From March of 2006, the polymer injection trial has been conducted on the A23 well when the water cut of the pattern was lower than 10%. After the trial, there were other 5 injectors (A1\A5\A10\A14\A18M) were converted to polymer injectors from 2007 to 2009. The polymer flooding controlled reserve was about 25,250,000 m^3.

Characteristic of gel-injection well effectiveness is shown in Figure 3 and Table 10. From the table we can conclude: injecting pressure rise, while water injectivity index decline and the values of RF and RRF remain above 1.

Number	Polymer concentration (mg/L)	Static adsorption (mg/g)
1	600	2.51
2	800	2.82
3	1000	3.13
4	1200	4.31
5	1400	5.16

Table 7: The static adsorption experiment result.

Displacement solution	Core permeability (10^{-3}mm²)	Polymer concentration (mg/l)	Dynamic adsorption (μg/g)
DQKY polymer	1096	1400	126
	1103	1200	95
DQGF gel	1133	1200	332
	1108	1000	226
DQGF polymer	1202	1200	104
	1100	1000	72

Table 8: The dynamic adsorption experiment result.

For the early stage polymer flooding, the characteristics of the responses on producers were different from the case in which polymer flooding was conducted during high water cut stage. The water producing of the producers continued to rise up after polymer flooding, but the simulation research showed that the water cut increasing rate was lower than the rate during merely water flooding (Figures 4-6). Of course, we also observed the drop down on the water cut in some wells, such as A11, A12, A13, A15, etc. For the well A11 (Figure 5), the highest water cut reduction reached 41% after the injectors (A5/A10) profiles controlled, and net incremental oil for A11 even reached 154,510 m^3.

By December 2014, the total incremental oil by polymer flooding was about 754,650 m^3, and the stage oil recovery efficiency was enhanced by 3.0%. And the polymer flooding is still effective now, and the polymer will be injecting until 2017. So we will get more oil from the polymer flooding. And the reasonable expectation of recovery beyond 2014 will be 2.8%. Totally we can get the oil recovery enhanced by polymer in LD oil field will be 5.8%. The actual EOR from polymer will be less than the plan of 6.1% EOR. The reason was that there were some wells blocked by polymer and sand. And we are doing lots works on solving the sand and polymer blockage [4,5].

Discussion and Conclusion

a. For the offshore oilfield, the platform life was about 25 years to 30 years. From lab test and numerical simulation research, we both know that the larger enhanced recovery value can be obtained, if polymer can be injected earlier.

b. We designed the polymer flooding on early stage, and the field test was carried out on the LD heavy oilfield of China offshore when the water cut was less than 10%.

c. By December 2014, the total incremental oil of polymer flooding was about 754,650 m^3, and the stage recovery was improved by 3.0%. The polymer flooding is still effective, and more oil will be produced by the polymer flooding.

Acknowledgment

The data presented in this paper was obtained from many other departments of CNOOC Ltd.-Tianjin, such as the production department and offshore department etc. And the polymer and gel suppliers also provided some laboratory test data. We would like to thank them all for their contributions to this work.

Injecting slug	Displacement pattern	Time (month)	Displacement agent	Slug concentration (mg/L)	Mother liquor concentration (mg/L)	Injecting pressure (Mpa)	Implementation date
First slug (0.0275 PV)	Gel	10	DQGF+crosslinking agents (P: Cr^3=600:1~60:1)	1200	5000 to 6200	<10	The polymer injection trial was conducted on the A23 well in March of 2006. After the trial, there were other 5 injectors were converted to polymer injectors from 2007 to 2009.
Second slug (0.11 PV)	Polymer	40	DQKY	1600			
Third slug (0.0275 PV)	Gel	10	DQGF+crosslinking agents (P: Cr^3=600:1-60:1)	1200			

Table 9: The dynamic adsorption experiment result.

Comparision before and after gel injection		A01	A05	A10	A14	A23	A35
Injection pressure (MPa)	Before	2.4	81	6.5	7.7	5.5	6.8
	After	12.2	12	12.2	12.4	12.5	6
	Increase value	9.8	3.9	5.8	4.7	7	-
Apparent injectivity index (m³/d/Mpa)	Before	11.4	102.8	104.5	90.7	107.5	122.2
	After	46.2	65	89.5	62.6	50.6	127
	Decrease percent	59.5	36.8	14.4	31	52.9	--
RF		2.3	1.5	1.3	1.5	3.6	Acidification

Table 10: Characteristic of gel-injection well effectiveness.

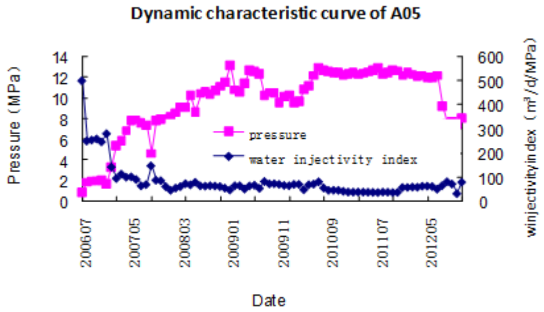

Figure 3: Dynamic characteristic curve of the polymer injector.

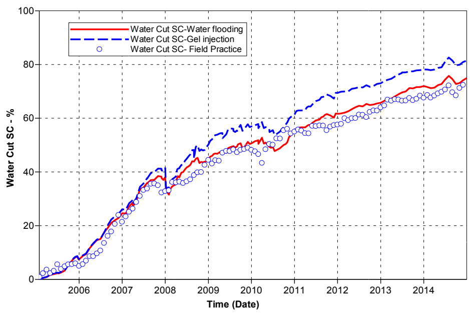

Figure 4: LD field history match curves of water cut.

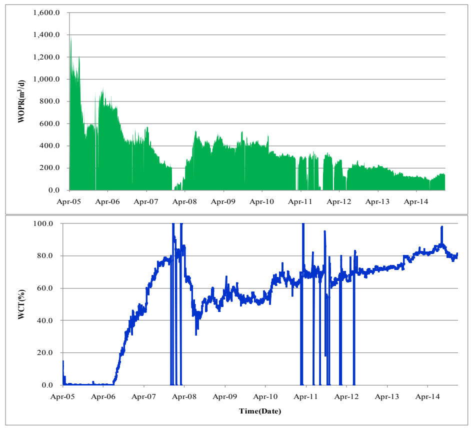

Figure 5: Production curve of producer A11.

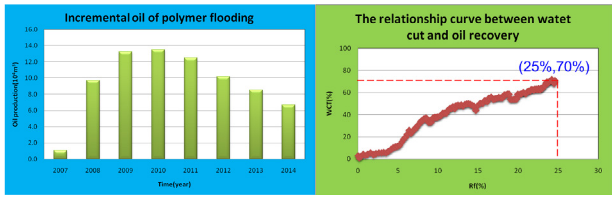

Figure 6: The effectiveness of the early stage polymer flooding.

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