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Research and Practice of Chemical Flooding on Offshore Heavy Oilfield in Bohai Bay of China

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Abstract

The Bohai Bay Basin is very rich in heavy oil. Generally the water flooding recovery of heavy oil reservoirs is only 18-20% in Bohai Oilfield, which has great potential for EOR. Being a mature technology in onshore oilfields, polymer flooding in Bohai Oilfield faces a serious of difficulties including choosing the best polymer injection opportunity in limited platform life, poor applicability of existing polymers and polymer preparation and production fluid treatment restricted by platform space. In recent years, several large heavy oil fields have carried out chemical flooding test. In order to solve the above problems, the early stage polymer injection development mode which breaks the limit of secondary and tertiary oil recovery was practiced to fit the service life of platform; a new kind of hydrophobic associative polymer was designed to meet the demand of viscous crude oil, high hardness water, strong shear force and large well spacing in Bohai Oilfield; a serious new facilities used for polymer instant solution and production fluid treatment was designed to fit the narrow space of platform.

The tests show that the early stage polymer injection development mode in offshore heavy oil fields has achieved good results. It effectively reduces or stabilizes the water cut and increases oil production significantly. Based on the good test results, the scale of injection test in Bohai Oilfield expands continuously. It develops from 1 injection and 5 production in a single well group to 44 injection and 171 production in three oilfields, with polymer flooding reserves reaching $144\times10^6m^3$. According to statistics, in the recent 5 years, the cumulative oil production of polymer flooding has reached $5.651\times10^6m^3$, and the recovery rate is increased by 3.9%, which is expected to be 8% in the future. Successful application of the technologies has significantly improved the development effect of offshore heavy oilfields. Even in the low oil price period, it has created tremendous economic value for the company. Nowadays polymer flooding has become a necessary means of stabilizing oil and controlling water in old oilfields in Bohai.

Introduction

More than 70% of offshore oil reserves in China are heavy oil, accounting for more than 50% of the total output. However, the water drive recovery rate is only 18-20%, which has great potential for EOR. In

this case, every one percentage point increase in oil recovery is equivalent to the discovery of a large oil field with 100 million tons of reserves without additional exploration investment. Due to the limitation of platform life, offshore oil fields have high demands for oil recovery rate. Thus it is necessary to enhance oil recovery as much as possible within the limited period of platform, which is a significant difference from the application of oil recovery technology of onshore oil fields. The field test of single well group was carried out in SZ oilfield in Bohai Bay in 2003, which opened the stage of EOR of chemical flooding in offshore heavy oil field. At present, chemical flooding pilot tests and field tests have been carried out in three different types of oil fields in Bohai Bay, including polymer and binary composite flooding.

The development practice of onshore oil field shows that polymer flooding can greatly improve oil recovery, but the offshore oil field is limited by harsh environment, technology and economic threshold, so it is a great challenge to improve oil recovery. The following three problems need to be solved in offshore oil fields when polymer flooding is widely used. First, the traditional oilfield development mode is divided into primary, secondary and tertiary oil recovery according to development time, that is, polymer flooding is used to enhance oil recovery in the stage of high or extra high water cut (>85%). Due to the limitation of offshore platform life (25 years), polymer flooding needs to be applied earlier, so innovative development mode must be developed. Second, in the face of the unfavorable conditions such as high viscosity of crude oil, high salinity of formation water, strong shear stress and large well spacing in Bohai oilfield, there is no polymer for oil displacement that can meet the performance requirements in the world, so new polymer for oil displacement must be developed. Third, restricted by the limited platform space, in order to implement polymer flooding in offshore oil fields, it is necessary to overcome the problems of platform polymer preparation and efficient treatment of produced fluid (Table 1).

Table 1—Comparison of parameters between offshore and onshore oilfields

Oilfields	Onshore oilfields (Example: Daqing/Shengli)	Offshore oilfields (Example: Bohai)
Viscosity of crude oil (mPa·s)	7~80	13.3~442.2
Salinity of formation water (mg/L)	2000~14000	65400~34000
Well spacing (m)	100~250	350~590
Well pattern	five-spot	inverted nine-spot/line
Space limitation(m^2)	--	55
Crude oil treatment facilities	Combination treatment station	--
Service life of equipment(year)	--	20~25

Field test and practice of chemical flooding in Bohai Oilfield

In order to solve the above problems, the early stage polymer injection development mode which breaks the limit of secondary and tertiary oil recovery was practiced to fit the service life of platform; a new kind of hydrophobic associative polymer was designed to meet the demand of viscous crude oil, high hardness water, strong shear force and large well spacing in Bohai Oilfield; a serious new facilities used for polymer instant solution and production fluid treatment was designed to fit the narrow space of platform.

Characteristics of chemical flooding in Bohai Oilfield

In order to determine the timing of chemical flooding, indoor physical simulation research and numerical simulation research have been carried out in offshore oil fields (Figure 1).

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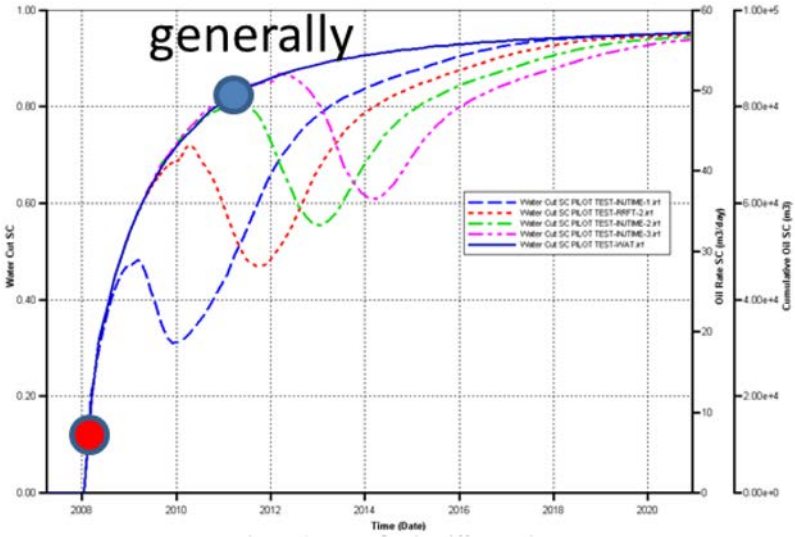

Figure 1—The EOR in different time

Under the limitation of platform life, in order to exploit as much oil as possible in the limited platform life, we propose an efficient development model of offshore oil field, which is "early water injection, water injection is polymer injection". Three oil fields were selected for polymer injection in different periods. LD oil field started polymer injection in low water cut period (8.5%), SZ oil field in middle water cut period (68%), JZ oil field in middle high water cut period (79%). The polymer injection period of the three oilfields is earlier than the high water cut to ultra-high water cut period of the onshore oilfields, which results in the different oil displacement rules from the onshore oilfields, and less data can be used for reference (Table 2).

Table 2—Characteristics of polymer injection in Bohai Oilfield

Oilfield	Viscosity in formation mPa.s	Water content %	Polymer injection well number
SZ	70	68	23
JZ	17	79	8
LD	14	8.5	6

For the first time in the world, Bohai oilfield has practiced the early polymer injection and high efficiency development mode. LD oilfield is injected and polymerized when the water content is 8.5%. By the end of 2015, it has realized the stage EOR of 4.1%. Based on the two-phase percolation mechanism of polymer flooding, we find that the best polymer injection timing is the peak of water cut rise, and the larger the viscosity of crude oil is, the earlier the polymer injection timing is. However, proper water injection before polymer injection is beneficial to maintain the polymer injection capacity of heavy oil reservoir and broaden the displacement interface rapidly, so as to obtain better sweep effect.

Design and development of special polymer for heavy oil reservoir

In view of the problems such as high viscosity of heavy crude oil, large distance between injection and production wells at sea and high salinity of water injection, the theoretical research of heavy polymer flooding was carried out, and a new generation of polymer for flooding, hydrophobic association polymer, was designed and developed. We introduce hydrophobic groups into the partially hydrolyzed polyacrylamide to make it associate, so as to create a reversible network structure. On the one hand, the polymer has high viscosity, high elasticity, strong salt resistance and lasting effect; on the other hand, it makes the shear thin and strong, effectively improving the injection effect. At the same time,

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the hydrophobically associating polymer enhanced the adsorption retention, obtained the appropriate high residual resistance coefficient, and significantly improved the interfacial viscosity. Hydrophobically associating polymer has been successfully applied in SZ oilfield, and has achieved better oil recovery effect.

Offshore supporting process facilities

In the stage of single well test and well cluster test, based on the characteristics of offshore platform and land experience, we independently developed the "intermittent preparation system" to meet the requirements of single well and well cluster injection and polymer flooding, so that offshore oil fields have the hardware foundation for polymer flooding. The system was put into use in SZ Oilfield in 2003. However, when the scale of polymer flooding is gradually expanded, the defects of "intermittent" preparation system, such as long dissolving time (120 minutes), more maturing tanks and large floor area, are gradually exposed. In order to meet the needs of large-scale application, we have applied the methods of polymer forced stretching, water infiltration and instant solution, and integrated many technologies such as pipeline mixing, multi-stage mixing of curing tank, etc. to realize the "continuous preparation" of polymer and ensure to meet the production needs of oil field.

The "continuous compounding" technology has significantly improved the compounding efficiency. Under the same compounding amount, the polymer dissolution time has been shortened from 120 minutes to 40-50 minutes, and the equipment area has been reduced by 21% and the weight has been reduced by 37%. It has been put into use in Bohai oilfield and widuri Oilfield in Indonesia since 2010.

Application effect of polymer flooding in Bohai Oilfield

The chemical flooding in three oilfields has achieved the effect of water control and oil increase, but the dynamic response characteristics are different. Through the establishment of mechanism model, we simulate the polymer injection process at different polymer injection time, and summarize the law of water content change (Figure 2). The reservior average porosity is 0.3, the average permeability is 3000mD,and the initial oil saturation is 0.65. The polymer concentration is 1750ppm,the viscosity of the polymer is 16mPa▪s,and the injection slug is 0.46PV. By comparing the results, we get two conclusions. (1) the shape of water content curve is obviously affected by polymer injection timing, which can be divided into two cases: with and without a downfunnel; (2) the later polymer injection timing is, the more obvious the water content downfunnel is; when polymer injection timing is 60% water content, a smaller downfunnel will appear, and then with the delay of polymer injection timing, the water content downfunnel is more and more obvious, so 60% is taken as the critical injection timing(Figure 3).

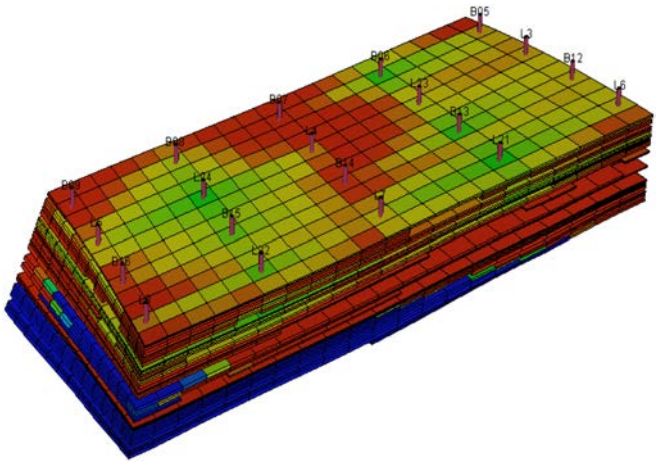

Figure 2—Mechanism model of polymer flooding

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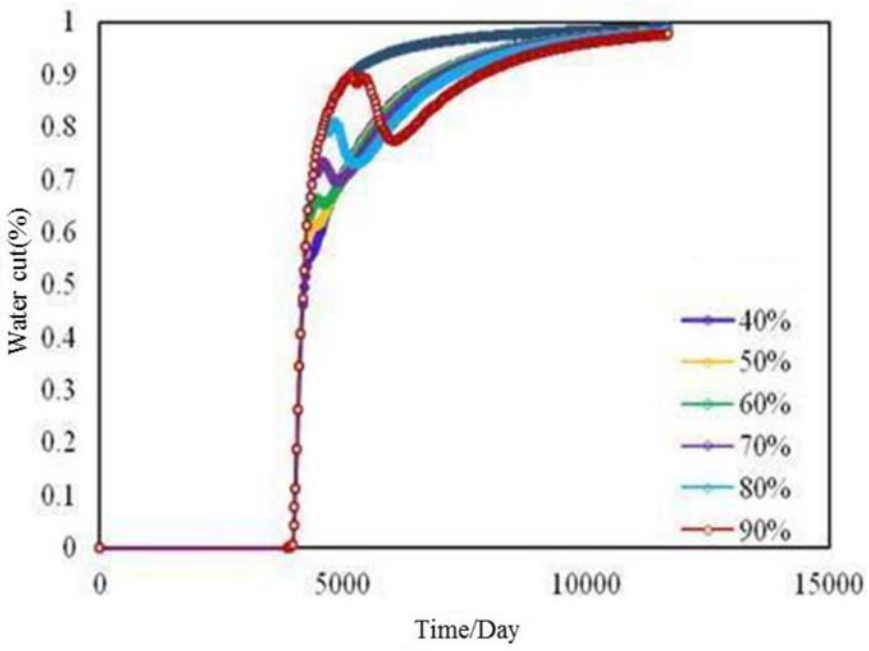

Figure 3—Watercut change curve of polymer flooding in different injection timing

For different injection stages, production wells show different patterns of effectiveness. The later the polymer injection time is, the more obvious the water cut depression funnel is. The main effective feature of early polymer injection is to control the water cut rise speed. The polymer injection effect of each oilfield is as follows.

1. JZ Oilfield

   JZ Oilfield started polymer injection when the water content was 79%. After polymer injection, the water content decreased and the oil production increased significantly. The average oil production of the production well before the effect was 40m^3/D, and the peak oil production after the effect was 65m^3/D, with an increase of 65%; the average water content of the single well decreased from 80% to 65%, with a decrease of 15% (Figure 4).
2. SZ Oilfield

   SZ oilfield started polymer injection when the comprehensive water content was 68%. After polymer injection, the water content of the oilfield did not decline significantly, but tended to be stable, which overall inhibited the water content rising speed (Figure 5).
3. LD Oilfield

   LD oilfield is an early polymer injection oilfield, and its water cut is less than 10% during polymer injection, so it is difficult to evaluate the polymer injection effect. On the basis of a good history fit, the numerical simulation analysis shows that the water cut of early polymer injection keeps rising and the effect of polymer injection is mainly to slow down the water cut rising speed (Figure 6).

   In order to better analyze the early polymer injection effect, the development effect of the experimental oilfield is compared with that of the water drive oilfield with similar geological conditions. Through the comparison of water cut rising speed of oilfield, it is found that under the same viscosity of crude oil, the water cut rising speed of LD oilfield is significantly lower than that of JZ oilfield, while the water cut rising speed of QK oilfield with lower viscosity of crude oil is comparable, which shows that the early polymer injection can significantly slow down the water cut rising speed of heavy oil oilfield (Table 3, Figure 7).
4. Oil increasing effect and EOR prediction

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Statistics on the effect of polymer flooding in Bohai oilfield show that by the end of August 2016, there were 3 polymer injection oilfields, 44 polymer injection wells, 171 polymer injection first-line wells and 5.651 million cubic meters of cumulative oil increase (Figure 8).

Table 3—Comparison of reservoir fluid characteristics in similar oilfields

Oilfield	Layer	Lithology	Porosity %	Permeability $10^{-3}\mu m^2$	Formation Oil Viscosity mPa·s
LD10-1	$E_3d_2^L$	coarse sandstone	26.1	400~2500	14.1
LD4-2	$E_3d_2^L$	medium-fine sandstone	22~30	50~1000	3.5~4.1
QK17-2	N_1m^L	medium-fine sandstone	32	1297	4.0~5.8
JZ9-3	$E_3d_2^L$	medium-fine sandstone	26.9	1432	10.0~26.0

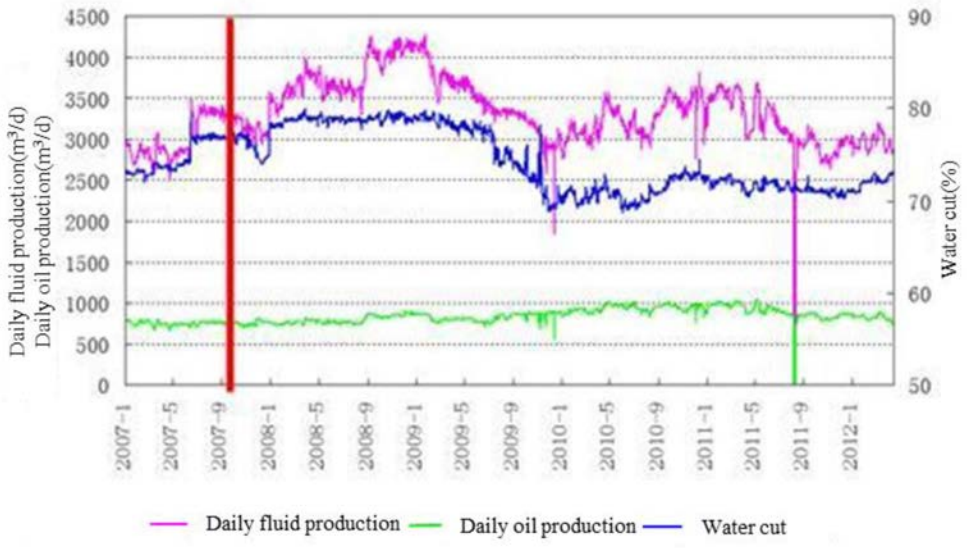

Figure 4—Production curve of polymer flooding in JZ Oilfield

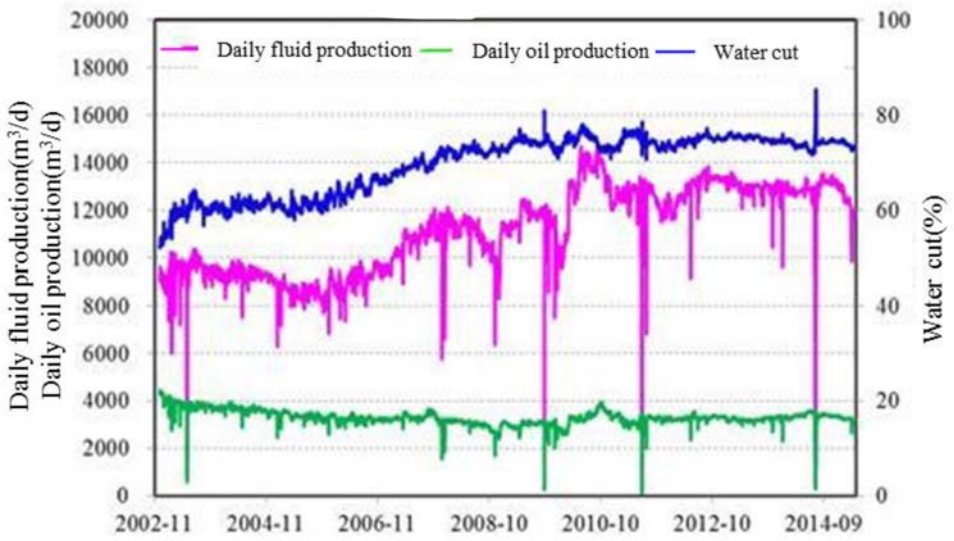

Figure 5—The effective characteristics of polymer injection in typical wells of SZ Oilfield

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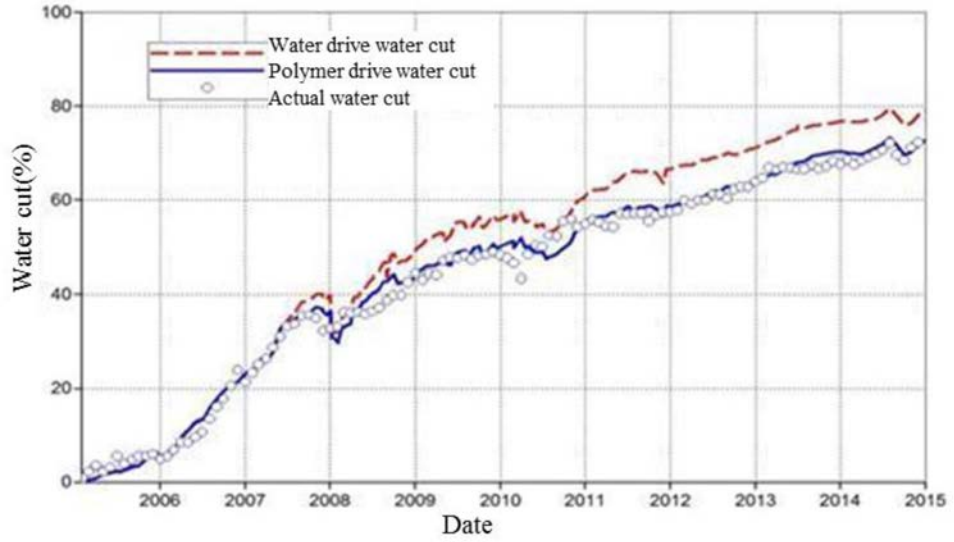

Figure 6—Production effect comparison of polymer flooding and water flooding in LD Oilfield

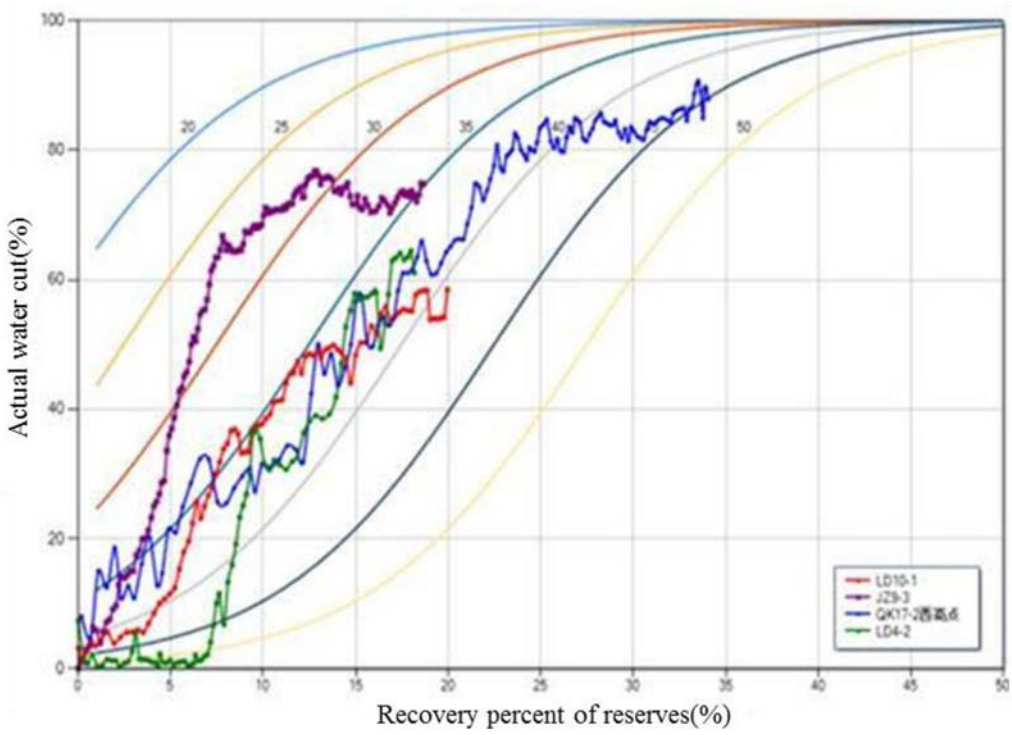

Figure 7—Comparison of water cut rise rate in similar oilfields

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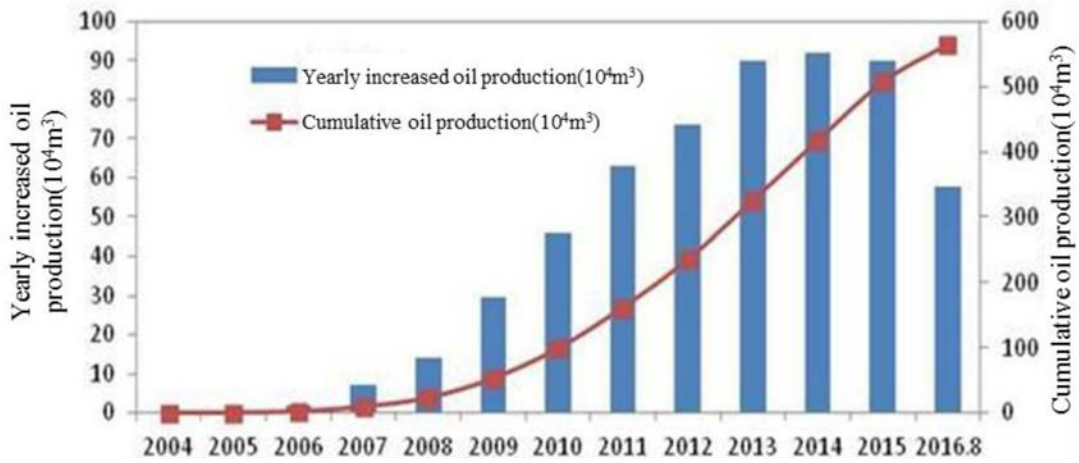

Figure 8—Oil increment of polymer flooding in Bohai Oilfield

Conclusions

1. The field tests of three polymer injection oilfields in the Bohai Bay are successful, and the timing of polymer injection in JZ,SZ and LD oilfield is different and earlier than that in onshore oilfields because of the limitation of platform life;
2. The characteristics of polymer injection are quite different from those in high water cut and ultra-high water cut stages in land-based oilfields;
3. Special polymer for heavy oil reservoir has been designed and successfully applied in SZ oilfield, and offshore supporting process facilities also have been improved for the needs of large-scale application.
4. There are 44 injection and 171 production in three oilfields in Bohai Bay, with polymer flooding reserves reaching $144\times10^6m^3$.The cumulative oil production of polymer flooding has reached $5.651\times10^6m^3$, and the recovery rate is increased by 3.9%, which is expected to be 8% in the future.

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