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Key Technologies of Polymer Flooding in Offshore Oilfield of Bohai Bay

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Abstract

Bohai Bay is one of the most important offshore oil production areas in China, and 74% of oil is heavy oil. For conventional heavy oil reservoirs, water flooding is applied normally with an inverted 9-spot flood pattern. The recovery is about 18~20% because of the heterogeneous and unconsolidated reservoirs. The current strategy for application of polymer flooding to enhance heavy oil recovery is based on the fully understanding of mechanisms and core technologies of polymer flooding in the laboratory research and field practice.

Single well pilot test and 5-spot flood pattern pilot test have been conducted in Bohai oilfield. The significant increase of oil production and reduction of water cut were observed. The limited life span of offshore platforms challenges operators to more effectively develop oil, thus it is necessary to identify the appropriate enhanced oil recovery (EOR) technology for use in a reservoir. Therefore, polymer flooding in early stage of oilfield development has been designed and conducted in Bohai oilfield. Five key technologies of polymer flooding concluded from the field practices were critical to the success of an EOR project and discussed in this paper. (1) Characteristics of polymer: polymer should tolerate high salinity and hardness of make-up brine. (2) Polymer injection technology: the technology should satisfy the requirement of offshore platform. (3) Modification of Polymer displacement under the big well spacing and multi-layer reservoir conditions. (4) Evaluation technology of polymer flooding in the early stage of oilfield development. (5) Production treatment technology of polymer flooding. This paper will focus on the impact of the five key technologies on development of offshore oilfields through introducing polymer flooding in Bohai Bay.

Introduction

It is estimated that about 74% of oil reserve in Bohai Bay is heavy oil, with the viscosities ranged from 50mPa·s to 10,000mPa·s. Currently the oil recovery by water flooding is around 20% OOIP, and most of oil is still remained in the reservoir. As a promising EOR technology, polymer flooding for offshore oilfield was studied for more than 10 years. Though some unsolved problems challenged the application of polymer flooding in offshore oilfield[1,2], Polymer flooding was adopted for improving heavy oil recovery in 2003. As a driving agent, polymer reduces the mobility of aquifer phase to force the remaining heavy oil. And as a mature EOR technology, polymer flooding is suitable for operation in offshore platform because it is not require complex and additional surface facilities in the relatively limited platform spacing. Based on the encouraging result of incremental oil in the single well pilot test, the polymer flooding was expanded to a larger pattern in October 2005.

The limited life span of offshore platforms challenges operators to more effectively develop oil, thus polymer flooding in early stage of oilfield development has been designed and conducted in Bohai oilfield. The success of the single well pilot test provided not only the amount of extra oil, but also some unexpected emerged situations with the polymer flooding scaled-up during field application. When it comes to the expansion of application of polymer flooding, more work has to be done in advance to avoid unexpected risks. Based on the understanding and experience from the previous work, five key technologies of polymer flooding were considered to show impact to encourage the widespread use of polymer flooding in offshore oilfield.

1. Characteristics of polymer: polymer should tolerate high salinity and hardness of make-up brine.
2. Polymer injection technology: the technology should satisfy the requirement of offshore platform.
3. Modification of Polymer displacement under the big well spacing and multi-layer reservoir conditions.
4. Evaluation technology of polymer flooding in the early stage of oilfield development.
5. Production treatment technology of polymer flooding.

A lot of work has undertaken, and is still keeping doing to make polymer flooding technology more suited for the offshore conditions. This work gives an overview of the five key challenges during the application of polymer flooding in Bohai heavy oil reservoir.

Single well pilot test

BH Oilfield is a typical offshore oilfield of Bohai Bay founded in 1987 and has put into production since 1993[1]. The average viscosities of oil is 70 mPa·s. Water flooding is the main recovery method. The adverse mobility ratio leads to early water breakthrough and high water cut. Before polymer flooding, the production degree is only 13.5% after over 10 years waterflooding.

Polymer flooding was considered to optimize the recovery of waterflooding. Hydrophobically associating water-soluble polymer was screened, and finally chose for the single well pilot test, because of its high viscosity and better performance in high salinity injection water.

Different onshore oilfield, the facilities on offshore platform should be portable, light, and easy dismountable with smaller size. A portable injection skid-mounted unit for the single well test was designed and manufactured to meet the requirement of polymer dissolving and injection rate.

The first single well pilot test ended in May, 2005 after 500-day polymer injection. A good result was achieved. Water cut decreased and oil production increased in the corresponding wells. The incremental oil was 25,000m^3 and water cut dropped from 95% to 54%. This test shows that hydrophobically associating water-soluble polymer is a proper driving agent for offshore polymer flooding.

Well pattern pilot test

Based on the experience from single well pilot test, the laboratory and numerical design, BH Oilfield well pattern pilot project was decided. Hydrophobcially associating water-soluble polymer was chose for the scale up test due to its good performance in the first stage application. The five-spot pilot area include four injection wells and six corresponding wells. Since October 30, 2005, polymer injection was conducted in four wells. As project planned in Table 1, total polymer consumed 3,142.7 tons in 3-year continuous injection. The total injected polymer solution would be 0.172 Pore Volume. Fig. 1 shows the production history of polymer flooding. After half year of polymer injection, oil production began to increase, and water cut dropped. Until April 30, 2008, after two and half year polymer injection, the four injection wells injected polymer solution $130.3\times10^4 m^3$ (i.e., 0.124 Pore Volume). The incremental oil production of six corresponding wells increased to $7.6\times10^4 m^3$.

Table 1. Planning of polymer flooding in well pattern pilot test to year of 2015.

Polymer consumption, tons	3142.7
Injection rate, m^3/d	1,640
Total polymer injection, $10^4 m^3$	179.58
Incremental oil production, $10^4 m^3$	18.9
Enhanced oil recovery by polymer flooding, OOIP%	3.0

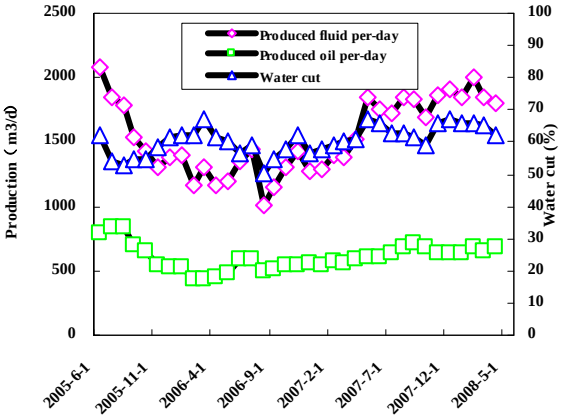

Fig. 1 Production curves of well pattern pilot test.

Key technologies

Single well pilot test not only provided us incremental oil, but also the lessons and experiences. It is necessary to well manage the risks and challenges for the expansion polymer flooding in offshore oilfield. Five key technologies challenge the application of large-scale polymer flooding.

Characteristics of polymer Besides polymer used in oilfield should be less shearing degradation, maintenance of quality of polymer solution and injection water for a long period is a real challenge to a success of a polymer flooding process. Salinity and hardness play a key role for viscosity maintenance of polymer solution. In order to make sure good performance in formation, polymer solution should be long-term stable and tolerate high salinity and hardness of brine.

Table 2 lists the compositions of original formation water, injected and produced water of BH Oilfield in history water flooding. It showed that the salinity of produced water is higher than original formation water, especially in Ca^{2+} and Mg^{2+} ions, as a result of firstly 8 years sea water, then source well water, and now the mixture of source water and produced water injection.

It is well known that the high Ca^{2+} and Mg^{2+} ions would dramatically decrease viscosity of polymer solution. From the beginning of screening polymer and the result of single well pilot test, polymer with high salinity resistance was what researchers most concerned. Modification and improvement of polymer characteristics never stopped. The research approach is outlined in Fig. 2 The ways to maintain a desired viscosity in high salinity and hardness water include to (1) adjust the polar monomers, (2) increase steric hindrance of intra-polymer molecules to enhance the rigidity of polymer long chain, and (3) increase functional monomers to enhance molecular interaction.

Item	Original formation water	Injected water		Produced water
		Sea water	Source well water	
Bicarbonate, mg/L	2,085	171	190	281
Carbonate, mg/L	231	0	0	114
Chloride, mg/L	1,573	18,168	5,470	9,288
Sulfate, mg/L	146	2,286	36	317
Calcium, mg/L	22	353	568	281
Magnesium, mg/L	14	1,231	228	238
Sodium & Potassium, mg/L	2,001	10,714	2,552	5,398
Total Dissolved Solid, mg/L	6,071	32,423	9,048	1,6116

Table2 Compositions of original formation water , injected and produced water of BH Oilfield.

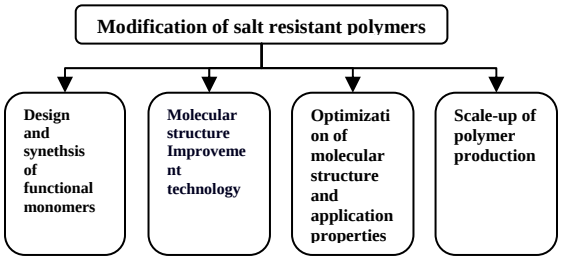

Fig. 2 Polymer modification methods

Polymer injection technology Platform weight and space restrict on retrofitted facilities for polymer flooding. The injection technology should satisfy the requirement of offshore platform. In an offshore environment, as a water-based process, polymer must be delivered to the facility, stored, treated, diluted and filtered, and injected through dedicated injection wells. As a result, the injection facility for polymer flooding in offshore oilfields must be the least weight and smallest size, portable, automatic, stable and skid-mounted. Besides those characteristics of injection facility should be, it is also be of crucial to fast dissolve for polymer solution in platform conditions.

In single well pilot test, polymer solution would dissolve in 60 minutes. It conveyed by the booster plunger pump and converged with the injected water so as to attain the dilute polymer solution in the static mixer. In single well pilot test, during the whole polymer injection period, polymer solution was injected continuously into well with injection rate of about 500 m^3/d and injection pressure of 6 ~ 8 MPa. This set of facilities is suitable for the requirement of single well polymer injection. However, with more wells to inject polymer solution, polymer dissolving rate could not satisfy the requirement of injection rate.

Polymer injection technology is focus on shortening dissolving time and keeping desired viscosity. There are two ways to get into it. Firstly, to investigate polymer dissolving mechanics for determining polymer dissolving process and main factors on the process. Then based on the mechanics, to design and scale up the proper fast dissolving equipment.

Modification of Polymer displacement under the big well spacing and multi-layer reservoir conditions The average well spacing of BH Oilfield is 370m. The oil-bearing zones belong to the lower section of Dongying, and the layer intervals is categorized into Layer I and Layer II which are principle oil producing zones. Each of them controls 8 and 6 substratum respectively and the thick oil layers. More work will be undertaken to modify and optimize flooding styles and flooding systems to shorten the timescale. Based on the experience from single well pilot test, two technologies, polymer flooding with in-depth fluid diverting technology and polymer flooding modification on heterogeneous thick oil layer technology will be taken into concerned. Fig.3 shows the technical routes of the two technologies for polymer flooding on big well spacing and multi-layer reservoirs.

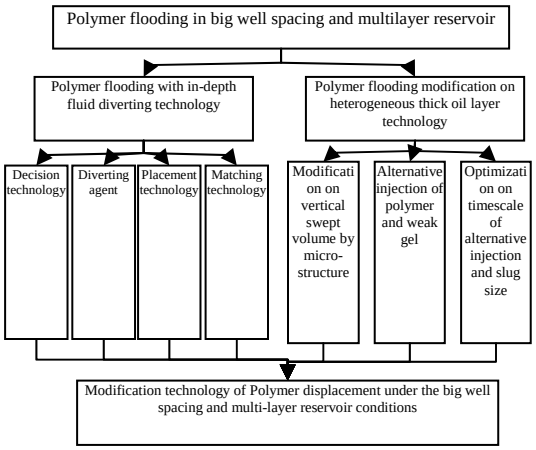

Fig. 3 Technical route of polymer flooding on big well spacing and multi-layer reservoirs

Evaluation technology of polymer flooding in the early stage of oilfield development It has to point out that the implementation of polymer flooding in Bohai Bay is in the early field life. The strategy of China offshore polymer flooding is early polymer flooding to achieve the most benefits in the limited platform lifespan. The challenge for reservoir engineer is how to evaluate polymer flooding efficiency without water flooding data as the baseline, and there is not much could be compared and referred from previous work.

It is necessary to establish an evaluation method to study polymer flooding in the early stage of oilfield development. From this point of view, four aspects of polymer flooding of offshore oilfield, including injection features,

operation features, development rules, and economic efficiency, are the key factors of evaluation technology. The detailed research ways are described in Fig. 4.

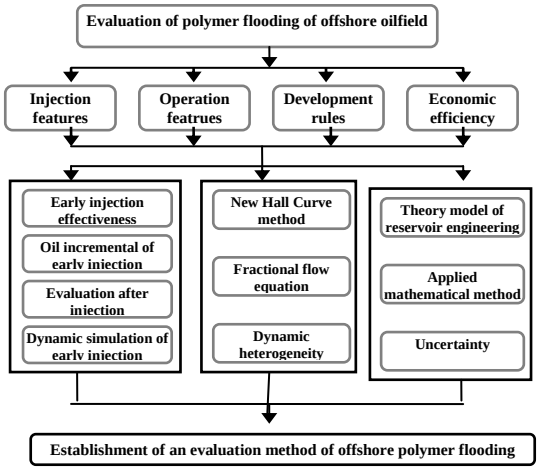

Fig. 4 Technical route of evalution technology of early offshore polymer flooding

Production treatment technology of polymer flooding As a water-based project, polymer flooding will become a water production project inevitably, and water production rates will exceed oil production rates. Thus, water disposal will become a sever problem. Because the produced large quantities of water and the separation of oil and water are not straightforward, considerable uncertainties will be inherent in the design of the process equipment and in the selection of the appropriate chemicals for removing produced polymers and demulsification.

It is hard to separate heavy oil and produced water contained polymer because the severe emulsification. A lot of work has been done on, and is still keeping investigating proper chemicals to demulsify heavy oil and water. In addition, the whole treatment process must be carried out on the platform. So, simple and fast have been taken into consideration for designing demulsfication process and select demulsification chemicals.

Conclusions

1. Field tests proved the feasibility of polymer flooding in China offshore heavy oilfield. Oil increasing was visible in single well pilot test and well pattern pilot test.
2. Five key technologies were concluded from the experience of pilot tests that would challenge the application of scale-up polymer flooding in offshore oilfield.
3. To achieve the most benefits should take the constraints of platform into consideration, such as the weight, spacing, and lifespan. Successful application of polymer flooding of offshore is a systematic work, full of modification, optimization, innovation, and integration.

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