The application of microbial combination flooding oil recovery technology in heavy oil reservoir with low temperature

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Abstract. HuabeiBaolige Oilfield belongs to the common heavy oil reservoirs with low temperature, which were tapped by the conventional waterflooding. The formation temperature of Baolige Oilfield is 38–58°C, and the oil viscosity of reservoir is 13.7–2000mPa•s. Thanks to the high oil-water viscosity ratio and strong heterogeneity, the small waterflooding swept volume and serious water breakthrough are caused by waterflooding fingering, causing that the workable reserve cannot be used efficiently during the oilfield development. According to the characteristic that the environment of the reservoirs is fit for the growth and reproduction of microorganism, the microbial enhanced oil recovery (MEOR) technology is used to improve oilfield development status. On the basis of continuous and further studies of MEOR, the industrialized application of MEOR has been fulfilled. By the continuous and further study, the efficient system of the combination flooding technology with oil displacement microbial fields was formed, and MEOR technologies have been enriched. All the above researches could provide technical ideas for the comprehensive treatment for similar blocks.

1. Introduction

In April 2004, the Ba 19, Ba 38, Ba 48 block was put into production. Late on, the Ba 51, Ba 10 block was built continuously, achieving production to succeed. In the process of waterflooding development, contradictions were increasingly apparent. On the one hand, with Ba 19, Ba 38 thin oil reservoirs, because of serious reservoir heterogeneity, large plane and interlayer contradiction and relatively high oil-water viscosity, swept volume of water flooding was small, the water cut rising speed was high, production decline was rapid. On the other hand, with Ba 48, Ba 51 ordinary heavy oil reservoirs, due to their high oil-water viscosity, water injection fingering is serious, water cut rising is fast, still in the low speed and inefficient development. Therefore, for the purpose of the overall improvement of oilfield waterflooding development effect, the overall management technology of waterflooding

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development to improve low temperature and heavy oil reservoir is researched and developed, which is the based microbial enhanced recovery of low temperature and heavy oil reservoir as the core, with gel displacement to improve the effect of microbial oil recovery. Through the large scale application of MEOR technology, microbial field had been preliminarily established, the cyclic microbial drive had been realized, production decline has been controlled effectively, the oilfield development effect had been improved effectively, solving the need of oil field production, filling the blank of the related technology of Huabei oilfield.

2. Basic conditions of reservoir

2.1. Geologic characteristics
Baolige oilfield is located in Bayindulan Sag north Sub-sag of Erlian Basin: Ba 19, Ba 38 block is located in BaⅡ tectonic zone, while Ba 48, Ba 51 block is located in BaⅠ tectonic zone (Fig. 1). Ba 48 block is monoclinal structure, while the other three blocks are fault-anticline structure, which more than one internal down faults are developed, making the structure further complicated.

![Fig. 1 Distribution map of Baolige oilfield](image)

The sedimentary environment is fan-delta front subfacies, the provenance is from the southeast, the main developed microfacies is the underwater distributary channel, mouth bar, distal bar, frontal sand sheet, subsea overbank sand, interdistributary bay and frontal fan-delta mud. Ba 19 and Ba 38 block is medium-porosity and low&medium-permeability reservoir, Ba 48 and Ba 51 block is low&medium-porosity and low permeability reservoir. According to formation test data, every block of fields is the normal pressure and temperature system.

2.2. Development characteristics
The water drive efficiency of thin oil reservoirs of BaⅡ tectonic zone is high, of which working condition is multidirection-based. The distribution areas of relatively coarse sand conglomerate, conglomeratic sandstone and fine sandstone are better working, while other lithologic distribution area is relatively poor. The producing degree and control degree of waterflooding of major reservoir is higher, and the control degree of waterflooding is up to 68.8%. The sand suction-production condition of oil layer is well, but the interlayer contradiction is prominent. Water cut rising is faster after water breakthrough, water cut rising rate is higher than the forecast. The water cut rising rate of Ba 19 block is high to 18.6% and Ba 38 block is high to 16.4%.

The waterflooding control degree of major reservoir in heavy oil reservoirs of BaⅠ tectonic zone is higher, but the producing degree is low. At the same time, the large longitudinal property differences lead to relatively large interlayer contradiction. Water absorbing capacity of 6.7% of the thickness in the water accepting layer is 59.7%, while liquid producing capacity of 21% of the thickness in fluid
producing layer is 73.9%. Ba 48 and Ba 51 block is breakthrough instantly when put into production. After water injection response, the water cut rising is rapid, initial water cut rising rate is as high as 62.4% and the calculated recovery of water drive is only 4.2%.

3. MEOR technology research

3.1. Research solution

From the basic study and understanding of the reservoirs, by using the static and dynamic contrastive analysis methods, the influence factors of causing injection-production contradictions are analyzed in-depth. According to the production features showed by every well group of reservoirs, management technical countermeasures is researched divisionally. On the basis of correct understanding of the reservoirs, further for the block and the main influencing factors, through the data query comparison and laboratory experiment verification, the technological measures for oil and water wells method are chose and studied, realizing the technology innovation in management thinking (Fig. 2).

In the study of technology, the technological method that lowers crude oil viscosity, controls the oil-water viscosity ratio and expands the formation sweep volume of microorganisms is the key research contents. By learning from mature theory and applying field test experience, combined with the laboratory evaluation experiment study, optimization design of the scheme is explored and completed. At last, the technical pilot field test is carried out step by step, to verify the reliability of technology. On this basis, facing the whole Baolige oilfield, deployed overall, implemented step by step, through the periodical and periodic technology implementation, the driving ability of formation oil is enhanced, the oil-water mobility ratio is improved, the water cut rising rate is controlled, the development speed is improved, realizing the industrial application of microbial recovery technique in Baolige oilfield.

3.2. Microbial technical system research

On the basis of the overall determinate thought, since 2007, through the related institutes cooperation, from the filtration of microbial strains with efficient production, species that can reduce the viscosity of crude oil are separated and domesticated and the evaluation method is constructed. And then the microorganism metabolites are analyzed qualitatively and quantitatively, establishing analysis standards of various metabolic products. The mechanism of MEOR is further understood, and the basic microbial flooding system has been established which is suitable for the Baolige oilfield (Fig. 3).
Eventually, 6 cases of microbial strains are determined by microbiological analysis and evaluation, of which emulsifying performance of indoor evaluation can reach more than level 4, average viscosity break rate is above 40% and average decreasing interfacial tension is 80% or more. At the same time, on the aspect of adaptability to environment evaluation, the screened six strains grow well under the condition of the reservoir temperature. Through the puncture test, these strains are confirmed as facultative anaerobe and grow normally in formation environment with dilute oxygen. They do not produce inhibition zone each other and the antagonism compatibility between the strains is well. In order to make full use of advantages of interaction between different strains, strain compounded system is established, whose performance evaluation is excellent and improved oil recovery in indoor physical simulation is above nine percent.

3.3. Gel flooding system research

In microorganism displacement process, because of reservoir heterogeneity, many problems are caused such as serious microbial channeling in the formation, being difficult to build microbial field effectively. Through technical research, under the condition of microorganism, gel formula system and injection technology is formed to satisfy the requirement of deep profile control of different reservoirs, which relieves effectively the reservoir contradictions between plane and vertical, inner layer and interlayer, and gives full play to the function of the microorganism field in the formation, to reach the aim to reduce oil viscosity, enhance the swept volume of injected water and improve the overall development effect of Baolige oilfield.

On the first stage, focusing on reservoir physical property and fluid property of Baolige oilfield, gel profile control technology system based on polymer-organic chromium is built. Considering that the formation temperature, fluid property and dosing water are the important factors influencing the gelling in the gel system, represented by Ba 19 and Ba 51 block, the laboratory experiment of formula system is carried out to determine the basic formula of gel profile control. Compatibility experiments show that the microbial and gel system has nice compatibility. Through physical simulation test of gel
profile control under the condition of microbial, oilfield development effect could be improved effectively. On the basis of laboratory experiments, field test is carried on. On the second stage, according to the field application situation, in view of the polymer gelling reaction mechanism and the effects of oxygen bearing in water on the stability of gel, the formulation of gel profile control system is optimized. On the basis of analyzing early profile controlling working practice in-depth, injection technology is perfected and optimized emphasizing from injection concentration, injection rate, injection volume and so on to improve the measures effect effectively. The optimum gel injection timing is determined through indoor physical simulation test. For the technical problems that conventional profile control system cannot realize sewage with fluid, low-temperature promoting agent of polyacrylamide and water soluble phenol-formaldehyde resin is researched and developed independently.

4. The field effect analysis
Since 2007, combination flooding technical critical of microbial and gel is carried out comprehensively in Baolige oilfield. Pilot test technology such as single well microbial stimulation, microorganism&gel combination flooding and cyclic flooding is taken on, and put into large-scale application. Since 2007, by measures such as single well stimulation, microbial flooding, gel flooding, natural decline is slowed down 2.3 percent. By saddle point method, the calculated cumulative increasing oil production is 190 000 tons, and the input-output ratio is 1:4.8(Fig. 4), obtaining the good economic benefit and social benefit.

![Production prediction curve of the Ba 19 block in Baolige oilfield](image1)

![Production prediction curve of the Ba 38 block in Baolige oilfield](image2)

**Fig. 4** Contrast curve of production

5. Conclusions
Through application of microorganism&gel combination flooding technology, the development effect of thin oil reservoir of Ba 19 and Ba 38 block is effectively improved, realizing the stable oil production, at the same time it shows that the combination flooding technology thought which set build underground microbial field as the core idea is correct and effective.

Using molecular biology techniques, the system analysis and evaluation of microbial oil recovery technology and monitoring technology after microorganism displacement is established, realizing the relative quantitative analysis of the component analysis, which has a guiding significance for further research of microbial oil recovery technology.

By using the principle of the bioreactor, floor fermentation and loop injection technology of produced liquid from micro flooding are innovated to form, realizing high reinjection of produced fluid.

For eight years, through the deepening research and field application, the system of microbial combination flooding technology is gradually enriched and improved, which has important practical significance on Huabei oilfield and even the similar oil reservoir of China petroleum.
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References
[1] Chen Yujun, Ju Dengfeng, Song Yiwei, et. 2005 Profile Control and Oil Displacement by Joint Function of WeakGel and Microbe (Special Oil & Gas Reservoirs vol 1) chapter 12 pp 84–86.
[2] Gang Wu, Fuping Ren, Jing You, et. 2013 Luteimonas Huabeiensis sp. nov., isolated from stratum water (International Journal of Systematic and Evolutionary Microbiology vol 9) chapter 63 pp 3352–3357.
[3] Ke Congyu, Wu Gang, You Jing, et. 2013 The Large Scale Application Research on Overall Microbial Flooding Technology in Baolige Oilfield (Oilfield Chemistry vol 2) chapter 30 pp 246–250.
[4] Ke Congyu, Wu Gang, You Jing, et. 2013 The Growth, Migration and Distribution Law of Microbes During Microbial Displacement Oil (Microbiology China vol 5) chapter 40 pp 849–856.
[5] Li Yongbin, Yu Lixin, Zhang Lili, et. 2013 Experimental Study of Microbial Flooding Physical Simulation for Baolige Oilfield (Oil Drilling & Production Technology vol 6) chapter 35 pp 95–97.
[6] Sun Sangdun. 2014 Field Practice and Analysis of MEOR in Shengli Oilfield (Journal of Oil and Gas Technology vol 2) chapter 36 pp 149–152.
[7] Lu Mansheng, Liu Zhicheng, Tang Sihong. 2012 Experimental Selection Method and Effect Evaluation of Microbial Enhanced Oil Recovery (Drilling & Production Technology vol 2) chapter 35 pp 90–93.